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A FRAMEWORK FOR EVALUATING
EVOLUTIONARY UPGRADE PATHS OF
COMMAND, CONTROL, AND COMMUNCATIONS
SYSTEMS

by

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June, 1993

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A Framework for Evaluating Evolutionary Upgrade Paths of Command, Control, and Communications Systems

by

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ABSTRACT

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I. INTRODUCTION

A. PURPOSE OF THESIS

The purpose of this thesis is to present a new framework for evaluating alternative evolutionary upgrade paths for command, control, and communications systems. Unprecedented changes in the international strategic environment, coupled with increasing domestic budgetary pressures, necessitated a shift in US defense strategy and are reflected in the new national military strategy published in January 1992. The new strategy shifts its focus from containing communism and deterring Soviet aggression to a more flexible, regionally oriented strategy capable of countering a wide range of potential threats to vital US interests. [Ref. 1:p. II-1] Guidance on changing C^4 systems and objectives have lead to initiatives such as C^4I for Warrior, the Navy's Copernicus concept, and the Navy and Marine Corp's "...From the Sea" strategy. Specifically, in the area of acquisitions, the use of an evolutionary type acquisition concept for the acquisition of new C^3 systems is now mandated by DoD [Ref. 2:p. 5-A-5].

Most C^3 systems that are procured today and in the future will undoubtedly incorporate incremental evolutionary upgrades during their useful life cycle. The author proposes a methodology for evaluating alternative C^3 systems that considers this temporal component by evaluating incremental upgrade paths.

B. METHODOLOGY

In order to understand the problems associated with evaluating C^3 systems, the major issues that effect C^3 system evaluation will be discussed. Then, the merits of some the current evaluation frameworks will be examined followed by the introduction of the new framework. To clarify the concepts introduced by the new framework, an illustrated example is presented using the United States Marine Corp's Tactical Combat Operations (TCO) system.

A major issue the new framework will address is the difficult, but ever present, <u>temporal component</u> of C^3 systems. The author proposes that effective evaluations of new C^3 systems <u>must</u> include an evaluation of its planned upgrade path toward some goal or target level of functionality.

C. SCOPE OF THESIS

The main focus of this thesis is to present a useful framework for evaluating evolutionary upgrade paths of C^3 systems. Only a general discussion of the important issues that effect evaluations will be given to characterize the evolutionary environment. The thesis will only address those issues that effect generic C^3 systems. After the framework is presented, an illustration will be presented using the TCO alternative systems established by the Marine Corps about the time of this writing. All values and costs used in the illustration are chosen for illustrative purposes only due to the unavailability of actual values.

In order to maintain a smooth flow between the discussion of the framework in Chapter III and the illustration in Chapter IV, the background and history of TCO and the Marine Tactical Command and Control System (MTACCS) will be presented in Section D of this chapter.

D. DEFINITION

The official Department of Defense (DoD) definition for a command, control, and communications system is:

> The facilities, equipment, communications, procedures, and personnel essential to a commander for planning, directing, and controlling operations of assigned forces pursuant to the missions assigned.

A command, control, and communications (C^3) system is a collection of tools the decision maker uses. It is a collection of facilities, equipment, communications, procedures, and personnel that helps the decision maker gather, process, and disseminate information. [Ref. 3:p. 1] With the increasing reliance on computer systems, the term command, control, communication, and computers (C^4) is also widely used. Likewise, C^4I and C^4I^2 have been popular terms that highlight the contributions of intelligence and interoperability.

To avoid confusion, the author will strictly use the term <u>C^3 system</u>. C^3 systems can also be viewed as a collection of tools that provide automated support to those functions that commanders have always performed (e.g., planning, directing and controlling his forces). Most operational Command, Control, and Communications (C^3) functions are done today, but the level of automation of each function varies from system to system.

Upgrades to C^3 systems will either fully automate a C^3 function or provide automated support to the function. In either case, it will be referred to as automating the function.[1] Some C^3 functions may even stay manual.

E. BACKGROUND AND HISTORY OF MTACCS AND TCO

The Marine Tactical Command and Control System (MTACCS) is the Marine Corp's current command and control concept and is compliant with the goals of C^4I for the Warrior. It stresses the integration of separate automation assisted Marine Air Ground Task Force (MAGTF) C^3 systems which support tactical operations. MTACCS enhances the commander's decision making capability and provides tools necessary for effective and efficient C^2 on the battlefield.

1. Background and History of MTACCS

a. The Need

The National Security Act of 1947 requires that the Marine Corps provide rapidly deployable amphibious forces for contingency missions in support of the national strategy. A key statutory mission of the Marine Corps is to provide MAGTFs for service with the fleet in the seizure or defense of advanced naval bases and for the conduct of such land operations as may be essential to the prosecution of a naval campaign. The coordination of such a large number of forces and equipment deployed over a wide geographic area demonstrates the requirement for an automated C^3 system to effectively manage the assets available. [Ref. 4:p. 1]

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[1] These aspects will be expanded upon in Chapter III.

An automated C^3 system that can be used in peace as well as combat would facilitate the prosecution of battle and make more effective use of available resources.

b. Historical Summary

The MTACCS concept started with C^2 studies conducted during 1965 and 1966, which resulted in the Marine Corps General Operational Requirements (GOR) No. CC-9, Marine Corps Tactical Command and Control Systems (MTACCS), issued in 1967. The USMC issued the first MTACCS Master Plan in 1976 to provide policy and guidance for the integrated management of efforts to improve tactical C^2. The last update of that plan was in 1981. Beginning in 1983, Headquarters Marine Corps (HQMC) incorporated the MTACCS Master Plan into the Marine Corps Command and Control Master Plan (C^2MP), last revised in August of 1987. Termination of the Marine Integrated Fire and Air Support System (MIFASS), a cornerstone of MTACCS in the original concept, caused the MTACCS philosophy to enter a two year period of dormancy. Only nominal integration of tactical data systems occurred during that period. The current MTACCS program will revitalize the original concept, update it to reflect the current needs of the MAGTF, and bring a modern tactical C^3 system to fruition. [Ref. 5:pp. 1-3]

The objective of the MTACCS concept is to provide MAGTF commanders with an integrated set of systems which can receive, process, display, store, and distribute essential information. Figure 1 portrays the MTACCS concept as it is currently envisioned.

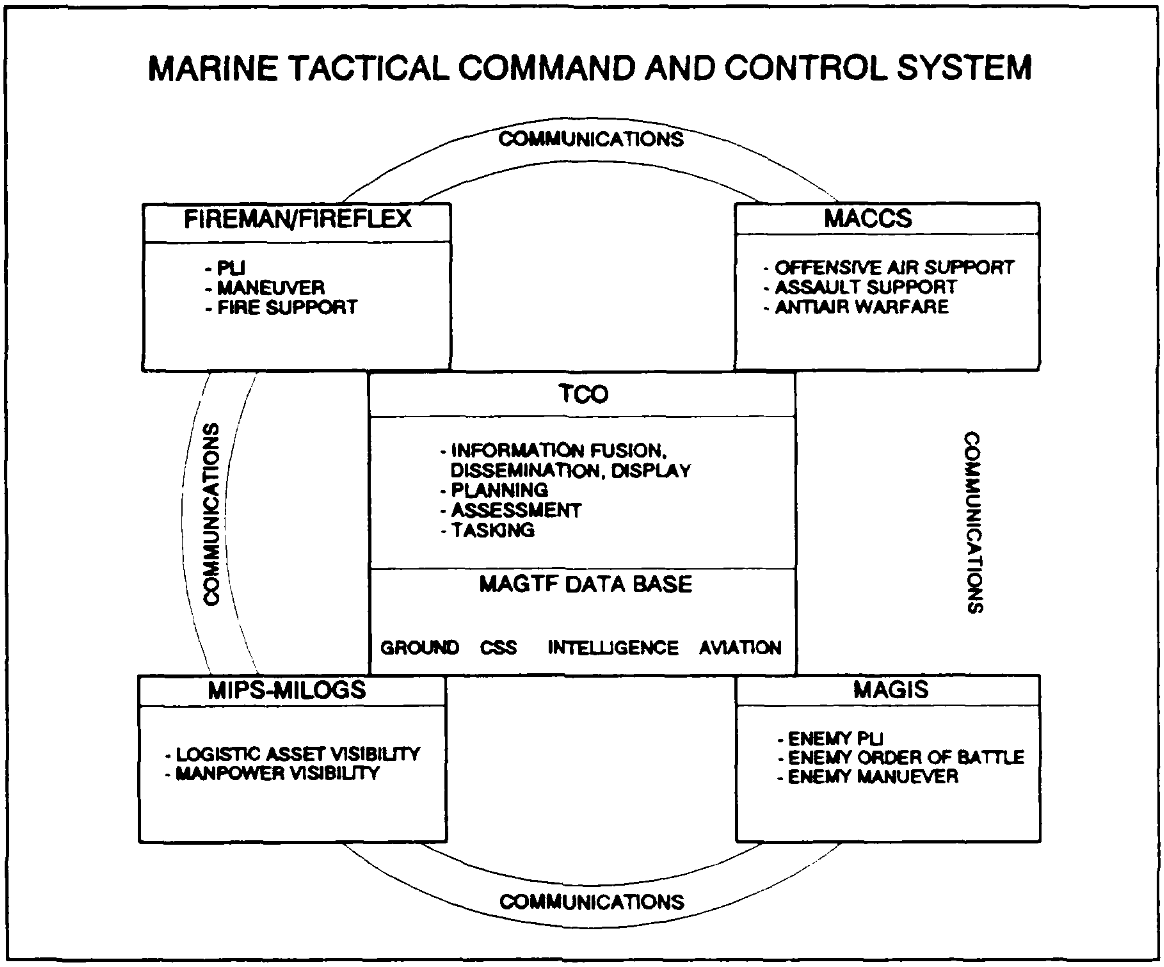

Figure 1: Marine Tactical Command and Control System

2. Background and History of TCO

a. Background

Marine tactical commanders face unprecedented challenges in exercising C^2 on the modern battlefield. The tempo of operations has increased, the MAGTF commander's area of interest has expanded, and more data is required to support tactical

decision making. The ability to gather, process, and disseminate tactical information is critical to the operational success of the MAGTF. The Marine Corps has long-recognized the need for an automated system to improve these C^2 capabilities and first identified this requirement as General Operational Requirement Number CC-9 of 28 July 1967. The requirement for the TCO system is documented in MNS, No. CCC 1.31A, approved by the Assistant Commandant of the Marine Corps and issued by the Commanding General, Marine Corps Combat Development Command (MCCDC), on 16 June 1992. Technology is now available to support development of a command and control system that will significantly enhance the commander's ability to plan and execute MAGTF operations. [Ref. 6:p. 1-1]

b. Operational Concept

The new approved standard general description of TCO as it is published in Campaign Plan 1- 93 is as follows:

> The Tactical Combat Operations (TCO) system will serve as the operations component to the Marine Tactical Command and Control System (MTACCS). TCO will use microcomputers to provide commanders the automation to receive, fuse, select, and display information from many sources, and disseminate selected information throughout the battlefield. TCO attributes include: automated message processing, mission planning, development and dissemination of operations orders and overlays, display of current friendly and enemy situations, display of tactical control measures, and interfaces with local and wide area networks. [Ref. 7:p. C-2-1]

TCO will be employed at the Command Element of the Marine Expeditionary Force (MEF), the Marine Expeditionary Brigade (MEB), and the Marine Expeditionary Unit (MEU). All staff sections of the MAGTF command element will interface with TCO. The system will support MAGTF commanders and their staffs

down to the battalion level in the Ground Combat Element, down to the squadron level in the Aviation Combat Element, and down to the battalion (and possibly company) level in the Combat Service Support Element. The principle users of TCO will be the MAGTF commanders and their operations staff. Operators will be watch officers and trained enlisted personnel.

The TCO system is designed to enhance the commander's ability to focus on critical elements of information while making battlefield decisions. It will use state-of-the-art technology to provide a mobile, flexible, and reliable system that is able to interface with existing Marine Corps, other services, and joint systems.

TCO will be composed of computerized workstations, connected by the designated Marine Corps standard local area networks (LAN) within each command post. These workstations will provide a graphical user interface and keyboard and/or pointing device; information processing and display; graphics; communications interface; and hard copy printout. LANs will be interconnected by wide area networks to other geographically dispersed command posts (CPs) via tactical communications assets. Separate, but reconfigurable, workstations are used for conduct of current operations and planning. This redundancy supports continuity of operations during CP displacement. [Ref. 6:p. 1-5]

3. Current Status of TCO

The Marine Corps Combat Development Command (MCCDC) Studies and Analysis Division is currently doing a Cost and Operational Effectiveness Analysis (COEA) on the selected TCO alternatives. These alternatives will provide automated

support for many of the functions presently handled manually in the Combat Operations Center. The following paragraphs outline briefly the current alternative systems being considered for fulfilling the requirements of TCO.

a. Base Case

This alternative would be to continue the status quo. Fleet Marine Force (FMF) units are currently using organic tactical communications, microcomputers, and the tactical digital facsimile to establish C^2 networks. These locally developed networks partially satisfy FMF requirements for automated support of operations planning and execution. Applications include locally developed programs tailored to support the needs of individual units as well as programs distributed Marine Corps-wide. However, they are unique to a particular MEF.

b. Maneuver Control System (MCS)

Under this alternative, MCS Version 11 software would be modified to satisfy TCO requirements. MCS is a component of the Army Tactical Command and Control System designed to provide support for operations planning and execution. Version 10 of MCS is currently fielded. Version 10 provides minimum capability and imposes a significant logistics burden. Version 11 is being developed by LORAL under contract to the U.S. Army Communications-Electronics Command. MCS Version 11 will collect, store, retrieve, process, and disseminate tactical information. A digital map and graphic overlay capability is provided. MCS Version 11 will operate in either a standalone or LAN configuration on a common set of computers from the Army Tactical

Automated Command and Control System Common Hardware and Software program. Communications interfaces are provided to the Army tactical communications networks, which include single channel radio, mobile subscriber equipment, and the Army Data Distribution System (EPLRS/JTIDS).

c. *Command Tactical Information System (CTIS)*

Under this alternative CTIS software would be modified to meet TCO requirements. CTIS is a C^2 system developed by and fielded within the Alaskan Command. CTIS currently operates in an Apple Macintosh environment and is being ported to a UNIX-based, open systems environment. CTIS uses commercial and tactical phone lines and commercial modems for data communications. CTIS provides the battlefield commander a tool for collecting, storing, processing, and displaying information. CTIS has a digital mapping and graphic overlay capability.

d. *Intelligence Analysis System (IAS)*

This alternative would satisfy TCO requirements through modification of the IAS. IAS is designed to support tactical intelligence collection, processing, and dissemination down to battalion level. The IAS is being developed by the Marine Corps Tactical Systems Support Activity (MCTSSA) at Camp Pendleton, California. IAS is currently hosted on a SPARC 2 server/workstation running a SunOS UNIX operating system. IAS supports generation of digital maps and overlays depicting the current situation. Information that can be displayed includes tactical control measures, targets, standard military symbology, and unit status data. IAS uses Defense Mapping Agency

(DMA) map products. Other capabilities include U.S. Message Text Format message preparation, ad hoc data base query, and generation of plans and orders. IAS Version 1.2 is currently fielded and has been used in a Special Operations Command Exercise by 24 MEU. Version 2.0 is scheduled for release during the second quarter FY 93 and will provide a substantial enhancement to IAS communications capabilities.

e. Combat Information Processor **(CIP)**

Under this alternative, the Marine Corps would continue the development of CIP to incorporate additional capabilities required for TCO. CIP was developed by the Advanced Sensors Systems Branch of the Harry Diamond Laboratories in support of the Amphibious Warfare Technology Directorate of Marine Corps Systems Command. This development was conducted as an advanced technology demonstration prototype. The CIP system is housed in an environmentally controlled Standard Integrated Command Post Shelter mounted on a M1037 High Mobility Multipurpose Wheeled Vehicle. The system provides situation awareness through a sophisticated digital map capability.

f. Naval Tactical Command System-Afloat (NTCS-A)

Under this alternative, the Marine Corps would extend NTCS-A to meet TCO requirements. NTCS-A is managed by the Space and Naval Warfare Systems Command and developed by the Research, Development, Testing and Evaluation (RDT&E) Division of the Naval Command, Control, and Ocean Surveillance Center. NTCS-A application programs include functional applications, such as the Joint

Operations Tactical System and the Naval Intelligence Processing System, incorporated into unified builds. NTCS-A relies on shipboard front-end processing and media access for local and external communications. NTCS-A can access various communications resources (AUTODIN, tactical link communications and TTY) through the communications server/front-end processor. The NTCS-A provides the Navy tactical commander the information necessary to plan and execute operations.

g. Maestro

Command Systems Incorporated (CSI) developed the FDS-1 TCO prototype. Since that time, CSI has continued to work on automated C^2 systems and is currently marketing a product called Maestro. Under this alternative, the Marine Corps would acquire the current version of Maestro and modify the software to meet the TCO requirements. The current version of Maestro runs on a DOS operating system. Maestro would have to be ported to run on the UNIX operating system using an X-Windows/Motif GUI. Maestro uses scanned paper maps and overlays to depict the current situation. Information that can be displayed includes tactical control measures, targets, standard military symbology, and unit status data. [Ref. 8:pp. iv-vi]

F. OUTLINE OF CHAPTERS

1. Chapter II. The Issues

In this chapter, the important issues of the emerging evolutionary procurement environment are discussed. Issues such as current technology initiatives, Evolutionary Acquisition, Non-Developmental-Items (NDI), Commercial-Off-The-Shelf

(COTS) products, and "open system" standards are presented along with their effect on the procurement of C^3 systems. The Mission-Oriented Approach (MOA), the Modular Command and Control Evaluation Structure (MCES), and the Cost and Operational Effectiveness Analysis (COEA) team's evaluation approach are presented to highlight the current methodologies and frameworks used to evaluate C^3 systems.

2. Chapter III. A New Framework

In this chapter, a new framework for evaluating evolutionary upgrade paths of C^3 system alternatives is presented. The framework is a functionally-oriented, capability-based approach that is intended to be a useful step by step method that produces valuable information about the upgrade paths of selected alternatives. Each step of the framework is presented along with recommended methods and procedures for accomplishing each step.

3. Chapter IV. An Illustrated Application

In this chapter, an illustration of the framework will be done using the Marine Corp's Tactical Combat Operations (TCO) system. The illustration will clarify how to apply the concepts and procedures of the framework. A simple step by step discussion of how to perform each step of the framework will be presented using subjective data do to the unavailability of actual data.

II. THE ISSUES

A. INTRODUCTION

Several recent initiatives such as DoD's Corporate Information Management initiative and the Joint Chiefs of Staff's "C^4I for the Warrior" plan have proposed new ways to do business. These initiatives serve to create a procurement environment that is business-driven, strategically planned, standards based, integrated, evolutionary, and more efficient. C^3 systems procured in this environment will utilize Evolutionary Acquisition and incorporate Non-Developmental-Items, Commercial-Off-The-Shelf products, and "open systems" standards.

In order to accurately and effectively evaluate current or future C^3 systems, the current and future environment in which they are acquired must be understood. This chapter will discuss aspects of C^3 system procurement today, the current C^3 technology initiatives, evolutionary acquisition, and open architecture standards. Some current evaluation frameworks will then be discussed to highlight the methodologies in use today.

B. C^3 SYSTEMS TODAY

C^3 system procurements today can be viewed as upgrades to existing C^3 systems. Most operational C^3 functions are performed today by commanders and their staffs with various levels of automated support. The procurements are intended to increase or improve this automated support. Even large procurements that make sweeping changes

(e.g., new C^3 systems) will be incremental and evolutionary. Therefore, it is useful to explicitly embrace the evolutionary upgrade concept, and develop a framework for comparing alternative upgrade paths rather than alternative static C^3 systems.

C. TECHNOLOGY INITIATIVES

1. Current State of Technology

America is in the midst of a technological revolution that will dramatically change the way companies and DoD do business. NCR Chairman and CEO Gilbert Williamson has said:

> "...The one constant of the information technology industry is change-rapid change...."[2]

This continuing changing nature of technologies will directly effect the C^3 systems that incorporate new technologies.

New, advanced technologies can permit significant restructuring in the way information is acquired, processed, and disseminated. Some functions requiring expensive and scarce resources can be centralized and automated to reduce required equipment, facilities, and skilled personnel. Reliable, wideband communications can enable centralized support to be rapidly provided to deployed forces. [Ref.1:p. III-15]

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[2] Taken from an article titled "Users Call the Shots, Says NCR CEO in Expo Keynote" in PC Week Magazine, 29 June 1992.

2. Key Technologies

In May of 1985, the Assistant Secretary of Defense for C^3I tasked the Defense Communications Agency[3] to undertake a projection and assessment of the impact of technology on the future C^3 systems of the DoD. DISA published the report called "Report of C^3 Technology Assessment" in January, 1987. The C^3 Technology Assessment concluded that the DoD should exploit technological opportunities to effect profound improvements in future C^3 system in the following areas:

1. To make C^3 systems "smarter";
2. To improve software productivity;
3. To provide for the distribution of C^3 assets for survivability; and
4. To cope with security vulnerabilities.

Above all, it will require further emphasis on systems engineering and technology transition; and the use of technology in <u>growing C^3 capabilities in place</u>, in contrast to <u>building C^3 turn-key systems</u>. The report highlighted that this will require further R&D work in seven major technology categories:

1. Distributed C^3 Systems.
2. Telecommunications Technology.
3. Command Decision Support Systems.
4. Information Security.

---

[3] Now called the Defense Information Systems Agency (DISA).

5. Software Engineering.

6. Artificial Intelligence.

7. Photonics.

The report stimulated the continuation of the C^3 technology assessment effort, including the conduct of additional workshops and the initiation of work on protocols and standards within the framework of an overall C^3 technical architecture. [Ref. 9]

3. The Effect on C^3 systems

Technological research will continually produce advances that will improve and streamline the way C^3 systems perform their mission. New advances will provide new capabilities that will enable current C^3 systems to provide better automated support to the C^3 functions it supports. As new capabilities become available, existing C^3 systems will incrementally add these capabilities by incorporating several upgrades during their useful life cycle. This results in a temporal component that must be dealt with.

The evolutionary acquisition concept has been recognized as the best way to incorporate these new technology based capabilities into existing C^3 systems. The following section will discuss this concept.

D. THE EVOLUTIONARY ENVIRONMENT

It has long been recognized that the standard DoD weapon system acquisition process is poorly suited to the acquisition of C^3 systems. Instead, an evolutionary process of "growing" a C^3 system-"build a little, test a little"-has recently been advocated. [Ref. 10:p. 6] The National Military Strategy Document for FY 94-99, the

"C^4I for the Warrior" plan, and DoD Instruction 5000.2, "Defense Acquisition Management Policy and Procedures", all mandate the use of evolutionary acquisition for the procurement of DoD C^3 systems.

In the late 1980's, General Alfred M. Gray (Commandant of the Marine Corps) put out initiatives to reorganize the Marine Corp's equipment acquisition and combat development processes. The evolutionary acquisition approach to command and control was adopted. A "build a little, test a little, field a little" strategy was put in place. [Ref. 11]

Section 1 will describe the evolutionary acquisition concept and discuss the advantages of it. The advantages and disadvantages of Non-Developmental Items and Commercial-Off-The-Shelf products will be presented in Section 3 and Section 4 will discuss how Evolutionary Acquisition will effect C^3 systems.

1. Evolutionary Acquisition

The "Evolutionary Acquisition" concept is a "build a little, test a little, field a little" approach using off-the-shelf equipment and software where applicable. Evolutionary Acquisition is defined as:

> An acquisition strategy which may be used to procure a system expected to evolve during development within an approved architectural framework to achieve an overall systems capability. An underlying factor in Evolutionary Acquisition is the need to field a well defined core capability quickly in response to a validated requirement, while planning through an incremental upgrade program to eventually enhance the system to provide the overall system capability. These increments are treated as individual acquisitions, with their scope and context being the result of both continuous feedback from developing and independent testing agencies and the user.... [Ref. 12:p. 23]

Evolutionary acquisition is an alternative acquisition process used to acquire C^3 systems that are <u>expected to evolve</u> during development and throughout their operational life. Figure 2 graphically represents the application of an evolutionary acquisition approach. The initial preliminary system architecture is segregated into planned increments. Those increments are then refined, funded, and developed in stages. [Ref. 13]

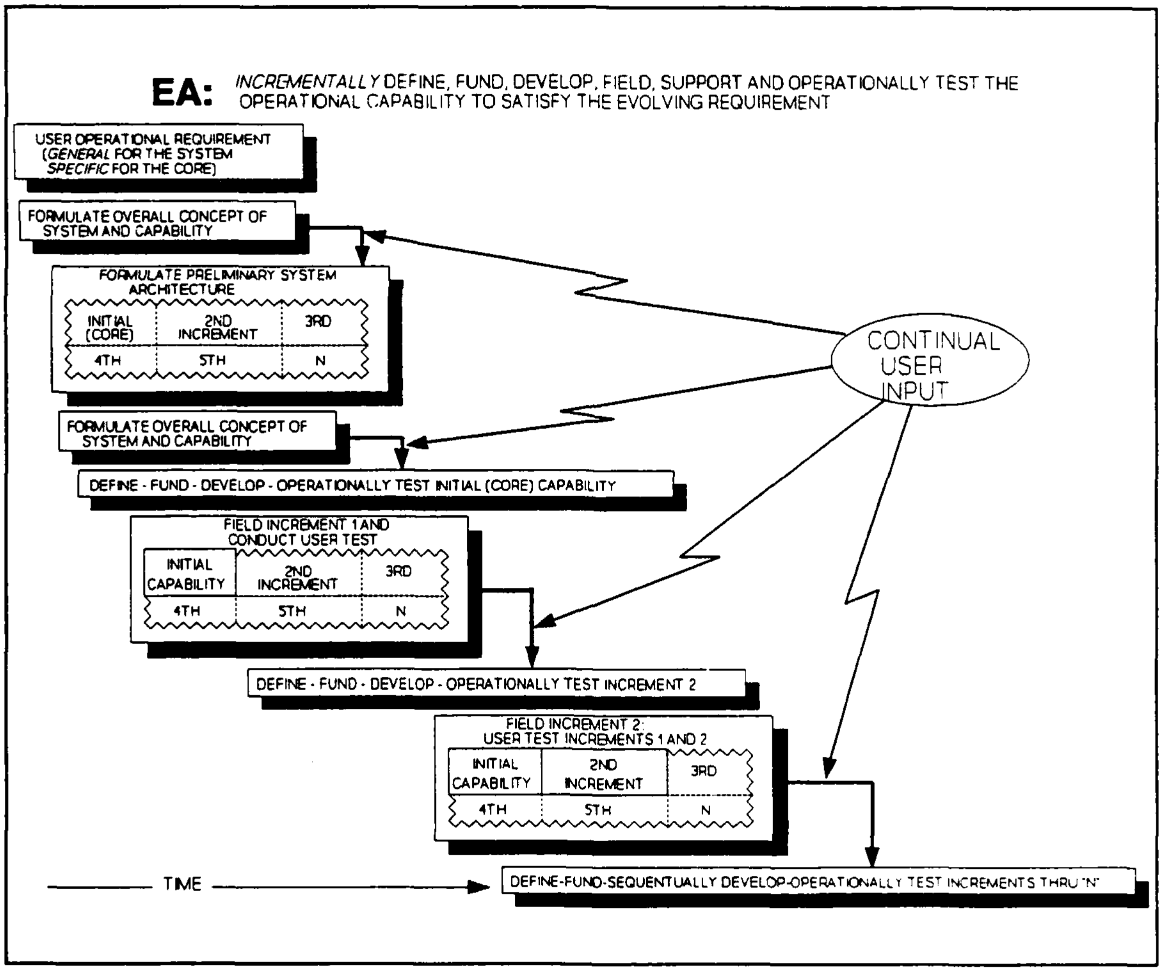

Figure 2: A Model of Evolutionary Acquisition

2. Advantages of Evolutionary Acquisition

There are several reasons for choosing an evolutionary acquisition approach:

a. Lessons Learned From Past Failures

The Marine Corps' attempt at the "big system approach" for acquiring the MIFASS[4] system has failed miserably in the past at extreme cost. [Ref. 14] It was simply too hard to adjust requirements and specifications to keep up with both user demand and technology, and quickly incorporate these adjustments into a system. [Ref. 15:p. 16] Using Evolutionary Acquisition, improvements or changes can be made at the next incremental upgrade and can be made easily if the original core design was built with the changes in mind.

b. Lack of Complete List of Defined Requirements

A complete list of C^3 automation or support requirements would be impossible to generate. The introduction of new technology and procedures makes old tasks easier and opens the door to provide new capabilities. This makes it difficult to predict the final requirements. [Ref. 15:p. 16] By using Evolutionary Acquisition, the user can provide timely, accurate feedback of what he/she wants, needs, and actually uses. This feedback can be applied to the next increment and tested.

[4] MIFASS was a subsystem program under MTACCS which failed for several reasons in 1987. A comprehensive discussion of MIFASS can be found in Chapter II of Reference 14.

c. *Political Acceptance of Evolutionary Acquisition*

The use of Evolutionary Acquisition as an alternative acquisition strategy is consistent with the guidance of the Office of Management and Budget Circular A-109, DoD Directive 5000.1, and with Defense Acquisition Circular 76-43. Evolutionary Acquisition encourages regular and continual interaction with the Deputy Program Managers[5], requirements proponents, users, developers, testers, and logisticians. It encourages the consideration of Non-Developmental-Items (NDI) and Commercial-Off-the-Self (COTS) material where applicable. [Ref. 15:p. 16] By this continual interaction, the risk of spending a large amount of resources with no measurable return is reduced. The program is reviewed by all concerned at each increment. Those responsible for certain fields will have to interact repeatedly with those responsible for the other fields that effect them.

d. *User Response is Quickly Incorporated*

By starting with equipment and procedures the user is already familiar with, and incorporating a limited amount of change at each increment, the user can easily assimilate and evaluate the change, providing appropriate and accurate feedback.

e. *Capabilities are Fielded Faster*

Evolutionary Acquisition permits faster fielding of core capabilities to the user. It allows building on existing equipment and systems to quickly field a useful core capability and concurrently develop component systems, capitalizing on the ability

[5] Deputy Program Managers are responsible for subsystems of a major acquisition program. They report to the Program Manager (PM).

to incorporate component systems as they complete their individual development phases. This permits new technology to reach the user at a rate that is much faster than currently possible.

3. Non-Developmental Items and Commercial-Off-The-Shelf Products

Non-Developmental Items and Commercial-Off-the-Shelf products are generic terms that describe material available from a variety of sources with little or no development be the government. These are items that are either available in the commercial market place or from other services.

According to William H. Taft IV[6], "The use of Off-The-Shelf sources is a major initiative of the Department of Defense [Ref. 16:p. 103]. There is considerable motivation to pursue this element of acquisition strategy wherever possible. Non-Developmental Items yield several benefits:

1. The time in development and the time to fielding is greatly reduced.
2. User's requirements and needs can be met and satisfied quickly.
3. Costs for Research and Development are reduced.
4. Current, state of the are technology is used and fielded. [Ref. 17]

[6] Former Deputy Secretary of Defense.

However, there are risks involved with using Non-Developmental Items. These include:

1. Cost and performance tradeoffs to accommodate the use of NDI components in production.

2. The resulting proliferation of hardware and software can cause logistic support, training, and configuration management problems and possible increased life cycle costs.

3. Safety deficiencies may occur because the NDI was not built specifically for a military environment. [Ref. 17]

The benefits of using NDI should aid in the fielding of C^3 systems tremendously. The risks are being minimized through the use of the common hardware and common software. By restricting the amount and type of each, many of the logistical and training burdens are alleviated.

4. The Effect on C^3 Systems

Most C^3 systems that are procured today and in the future will undoubtedly incorporate incremental evolutionary upgrades during their useful life cycle. Evolutionary Acquisition will be the strategy used to accomplish this. Brigadier General Edward Hirsch[7], USA (Ret.), wrote in an article in *Signal* magazine:

> Evolutionary Acquisition is not a cure-all for the real or perceived ills of the U. S. acquisition process; but it does hold some promise to help field command and control systems sooner, at lower cost and with higher user satisfaction than other approaches. [Ref. 12:p. 23]

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[7] Director, Center for Acquisition Management Policy, Defense Systems Management College at the time of publication of the article.

Evolutionary Acquisition has gained wide recognition as a strategy that provides the flexibility necessary to adapt evolving C^3 systems.

E. THE OPEN ARCHITECTURE ENVIRONMENT

1. Overview

A current approach to eliminating the problems of incompatibility, while transcending the problems of centralized systems, is called the "open systems" approach. There is a trend within the industry to develop products according to government, international, and industry standards. Users, vendors, and government standards organizations are encouraging the development of open system architectures. According to the International Organization for Standardization and the International Electrotechnical Committee (ISO/IEC), an open system is a system that complies with the requirements of a given set of universally accepted standards for communication and interacting with other open systems. Advantages of adopting open system architecture standards are the following:

1. Increased competition results from the variety of vendors manufacturing products to meet the specified standards.
2. Interoperability and portability are attainable only with systems using the same standards.
3. Open systems support a multivendor environment, which reduces the chance that the government will be dependent on a single contractor.

Although a potential logistics risk is created by a multivendor environment, this can be managed by requiring that all products purchased be contained on a list previously

established by the government. [Ref. 18:p. 2] The principle disadvantages of using standards are:

1. A standard tends to freeze the technology. By the time a standard is developed, subjected to review and compromise, and promulgated, more efficient techniques are possible.
2. There are multiple standards for the same thing. This is not a disadvantage of standards *per se*, but of the way things are currently done. Fortunately, in recent years, the various standards-making organizations have begun to cooperate more closely. Nevertheless, there are still areas where multiple conflicting standards exist. [Ref. 19:p. 18]

2. The Effect on C^3 Systems

Currently evolving open system standards include POSIX[8] interfaces, GOSIP[9] data communication protocols, the ADA programming language, SQL data management systems, X-Windows User interfaces, Motif Graphic services, and X.400 message handling systems. [Ref. 8:p. 3-61] Since these standards are still evolving, C^3 systems developed in an open systems architecture today should have an integration plan that allows for the smooth incorporation of future evolving standards.

The use of open systems standards such as GOSIP is now a federal information-processing standard (FIPS) and is mandatory for use on government procurements [Ref. 19:p. 27]. C^3 systems that are developed using open system architectures reduce system integration costs; increase freedom of choice in selecting

[8] Portable Operating System Interface; X denotes its UNIX origin.

[9] Government Open System Interconnection Profile.

vendors; protect investments in software, data, and people; and enhance availability, quality, and variety of complementary products. [Ref. 20]

F. CURRENT C³ SYSTEM EVALUATION FRAMEWORKS

This section will discuss some of current frameworks used today for evaluating C³ systems.

1. The Mission-Oriented Approach (MOA)

The Mission-Oriented Approach is a framework for formulating requirements in order to achieve the desired balance among mission support, technical capability, and resources. This approach systemically and consistently addresses four interrelated questions (see Figure 3).

First, it addresses the question "What are we trying to achieve operationally?" This question must be answered by high-level decision makers in the context of relevant policy and political-military considerations. The response is generally cast in terms of a set of strategic capability objectives for employing forces. These force capability objectives provide the standards against which the capabilities of existing and proposed packages of information systems can be measured.

The second phase of the requirements process addresses the question: "How should we perform the mission operationally?" This question must be addressed by operational personnel who must formulate concepts of operations at multiple levels: strategic (e.g., the concept of forward defense), operational (e.g., mix and emphasis among missions), and functional capability (e.g., ability to sense, assess, plan, and direct

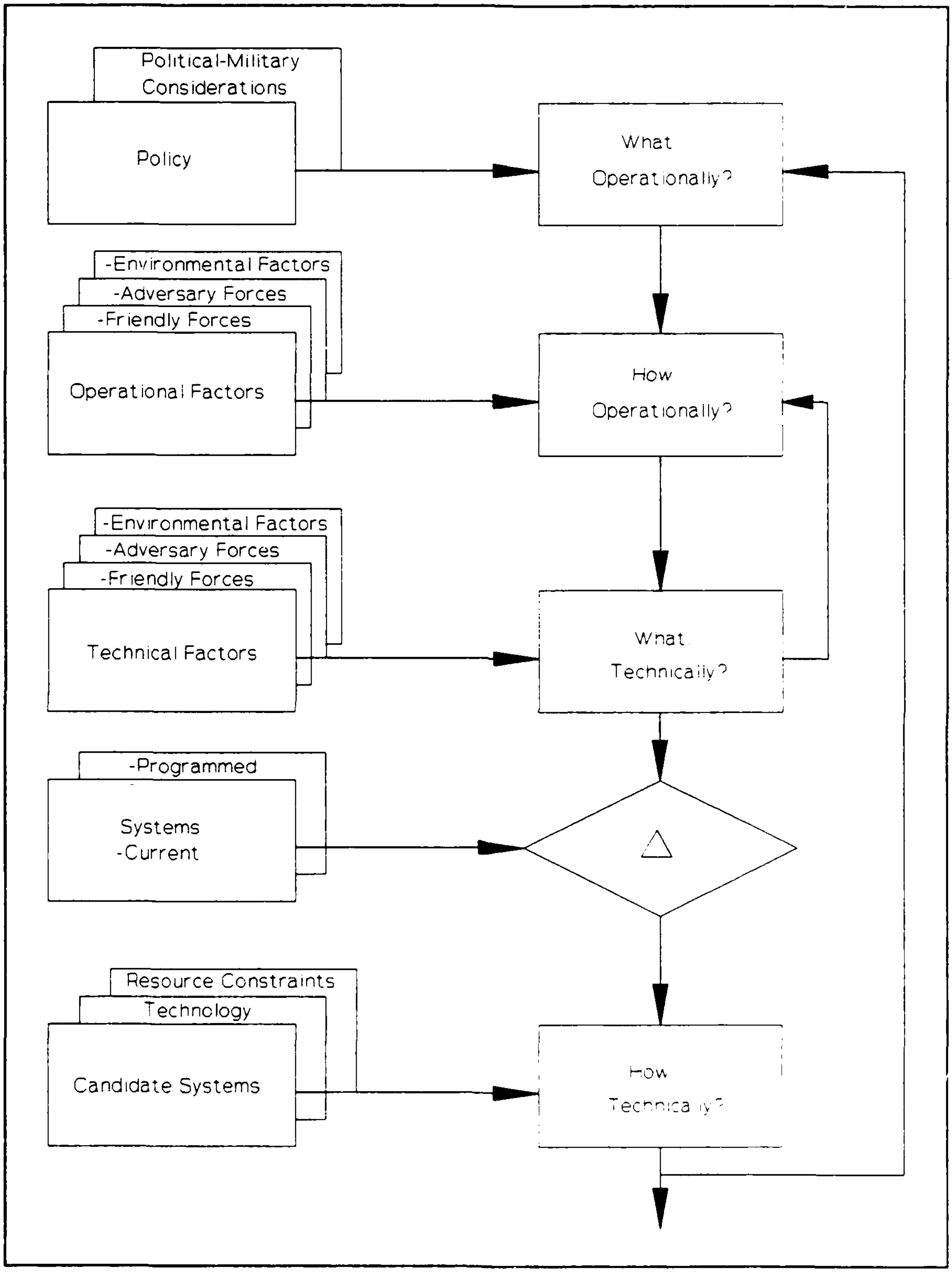

Figure 3: The Mission-Oriented Approach

to achieve mission goals). The capability objectives for each of these levels must be derived self-consistently, beginning with specified strategic capability levels, based on likely adversarial operations, friendly concepts of operation, and environmental factors.

The third phase of the requirements process addresses the question: "What technical capability is needed to support the operation?" This phase should employ technical personnel to translate the operational capability objective levels into the desired technical attributes of the information systems needed to implement those capability levels. These technical capability objectives are derived using the existing and projected technical characteristics of adversary forces, friendly forces, and environmental factors.

The fourth phase of the requirements process addresses the question: "How is the technical job to be accomplished?" As a foundation for this question, technical deviations are identified be comparing the technical capabilities of existing and programmed information systems to the time varying technical capability objectives identified in the prior phase. Based on those deviations, technical and programmatic personnel can formulate technical requirements that are consistent with assumptions on available resources and schedule. If these communities are to perform this task credibly, it is critical that they be cognizant of the unique characteristics of information systems. These systems are characterized by internal and external interfaces that are complex, frequently changing, and at multiple organizational levels. Humans are integral parts of these systems and their interfaces with one another and the machines are highly interactive, complex, and changing. The technology that underlies these systems (e.g., computers, communications, displays) is undergoing revolutionary change and emerging

systems are very software intensive. Thus the technical and programmatic communities face the challenging task of formulating technical requirements that balance technological risk and obsolescence. [Ref. 21:pp. 119-128]

After initial answers to these four questions have been developed it is important to iterate through the framework. This iteration is needed to identify and resolve issues that require additional analysis across communities (e.g., interaction between the operational and technical communities) and within communities (e.g., technical tradeoffs between risk and potential obsolescence). [Ref. 22:pp. 2-5]

The Mission-Oriented Approach is an attractive candidate for formulating C^3 system requirements in an evolutionary environment. A variation of this approach has been successfully used by U.S. Pacific Command (USPACOM) to help identify and define C^3I capabilities and systems that their warfighters need to meet USPACOM mission responsibilities. [Ref. 23]

While the Mission-Oriented Approach is well suited for requirements determination, it is not particularly well suited for the evaluation of alternative C^3 systems, which is the focus of this thesis. But, the approach could be used to verify or validate current and future C^3 system requirements.

2. The Modular Command and Control Evaluation Structure (MCES)

The Modular Command and Control Evaluation Structure (MCES) is a general approach to evaluating C^3 systems which has been successfully applied to a number of issues concerning C^3 system planning, acquisition, testing and operation. [Ref. 24] It augments traditional analysis by providing a series of seven steps or modules to

evaluate alternative C^3 systems and architectures. These modules guide analysts who might otherwise focus prematurely on the quantitative model rather than the problem definition and the specific measures needed to discriminate between alternatives. The seven steps of the MCES are briefly described below including the product of each module.

The MCES begins by identifying the objective of a particular application. This leads to a formal problem statement. The second step is to bound the C^3 system involved, by producing a complete list of system elements at several levels. The third step is building a dynamic framework that identifies the relevant C^3 process-a set of functions. The fourth step combines the results of steps two and three by integrating the system elements and the process functions into a model or representation of the C^3 system. The product of this module is at least a complete descriptive conceptual model and sometimes a complete mathematical model. The next (fifth) step is to specifically identify measures of performance, effectiveness and force effectiveness at the corresponding levels of the C^3 system and function. The sixth step is to generate results or values for these measures by testing, simulation, computational modeling or subjective evaluation. Finally, the various measures are aggregated and interpreted in the last step. The seven steps of the MCES are performed iteratively with the decision maker as shown in Figure 4.

In an area such as C^3, standard language and paradigms are difficult but necessary. The MCES was developed by a team of experts from industry, government and academia and was endorsed by the Military Operations Research Society. It presents

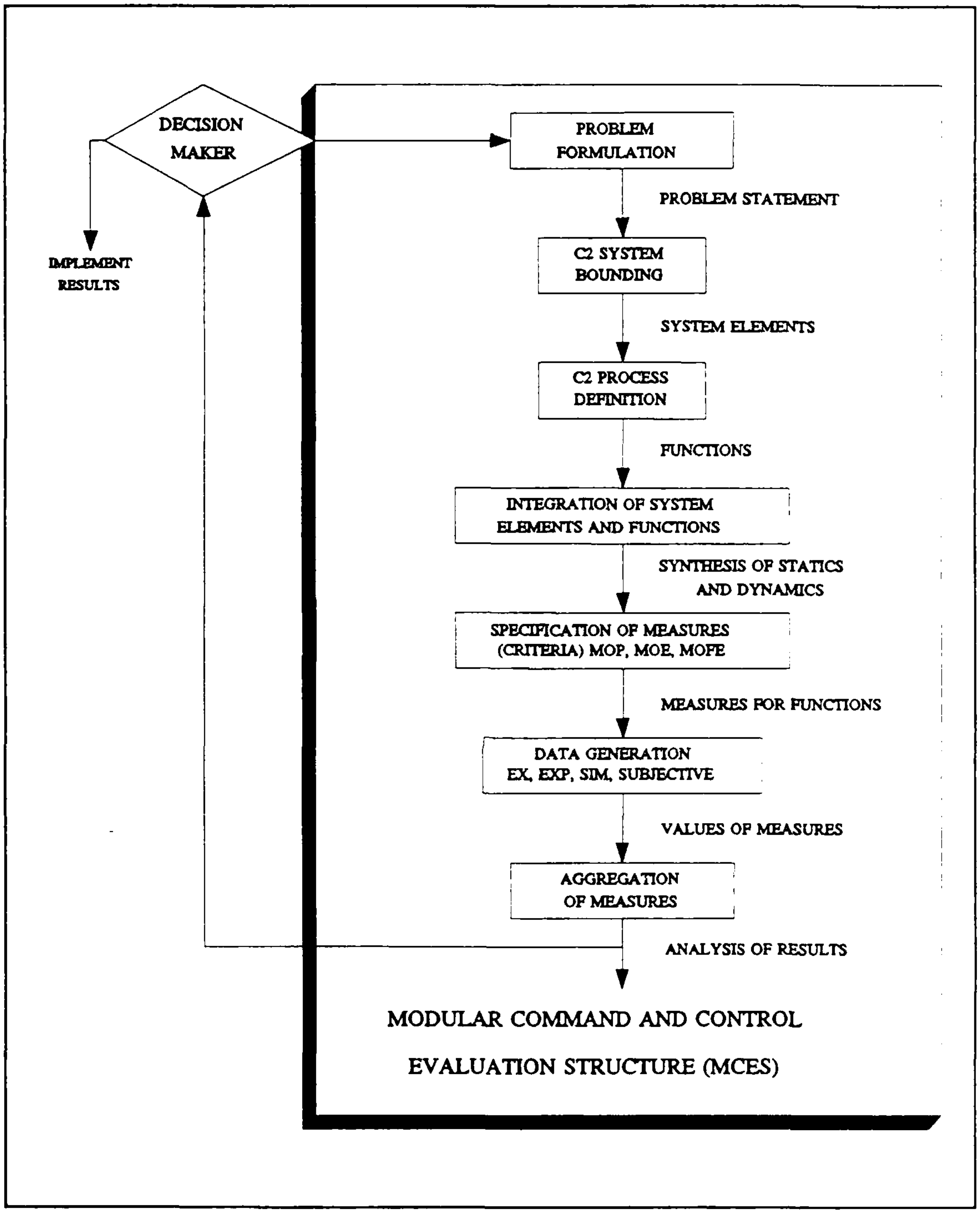

Figure 4: Modular Command and Control Evaluation Structure

difficult concepts in a standardized way that is easily absorbed by both new practitioners and managers. MCES has potential for reducing mis-understandings of the purpose and

mis-applicability of analytical results. This is important when issues of great diversity of nature, size and level of detail are being considered. Standardization of analytical procedure can be advantageous if based on a comprehensive and rigorous methodology such as MCES. The MCES can be used for studies ranging from the quick conceptual level to the complete quantitative study. [Ref. 25:pp. 1-3]

The MCES offers a comprehensive framework for developing robust measures for complex systems, but it doesn't provide specific guidance on evaluating systems that will change over time. An interesting similarity exists between the Mission-Oriented Approach and the Modular Command and Control Structure. Note that the first two questions of the MOA and module three of the MCES both deal with C^3 functions. Also, the second two questions of the MOA and module four of the MCES deal with C^3 components or capabilities to support those C^3 functions.

3. The Current COEA Evaluation Framework

The following sections will present the methodology used by the Cost and Operational Effectiveness Analysis (COEA) team for the evaluation of the Marine Corp's TCO program discussed in Chapter I.

a. Approach

Each alternative was evaluated in three areas: effectiveness, cost, and risk. The effectiveness evaluation was conducted by an evaluation team exercising each of the alternative systems in a laboratory environment. The cost evaluation was conducted by collecting cost data from developers; the TCO program office; Marine

Corps Tactical Systems Support Activity (MCTSSA); Marine Corps Logistics Base, Albany; the MTACCS Common Application Support Software program and MTACCS Common Hardware Support programs; Marine Corps Operational Test and Evaluation Activity; civilian vendors; and the Marine Corps Cost Factors Manual. This data was validated and expanded using the Constructive Cost Model and the Conversion Cost Model. Both of these models predict software development costs based on system size and complexity. The Conversion Cost Model specifically addresses costs associated with software conversion. Discounted life cycle costs were estimated using the Marine Corps Summary Version Life Cycle Cost Model. The risk assessment assessed the technical and program risk associated with modifying each of the alternatives to satisfy the TCO requirement.

b. Effectiveness Analysis

Evaluation of the effectiveness of TCO alternatives focused on determining the operational effectiveness, the operational suitability, and the life cycle supportability of each alternative. To this end, measures were developed to support assessments of capability in each of these three areas. Measures of operational effectiveness assess the military utility of each alternative. Measures of operational suitability assess how well each alternative would operate in an austere environment without adversely impacting mobility, maneuverability, or operational flexibility. Measures of life cycle supportability assess sustainability, maintainability, and growth potential. These measures were based upon the TCO requirement as documented in the TCO MNS. Overall rankings were assigned.

c. Cost Analysis

Life cycle cost estimates were developed for each TCO alternative. These show the costs to satisfy TCO core requirements and the incremental cost to satisfy follow-on requirements. Life cycle costs include research, development, testing, and evaluation (RDT&E); procurement; and 15 years of operations and support (O&S). RDT&E costs are associated with software development, operational test and evaluation, system integration and assembly, and program management. Procurement costs include hardware, spares, and repair parts, commercial software, contractor-provided training, and first destination transportation. Operations and support costs include software and hardware maintenance, operator training, and secondary destination transportation. Estimates were based on implementation of MCHS Class B hardware and MCASS software. An additional $1,500,000 per year has been estimated to support evolutionary, system improvements. The core, follow-on, evolutionary and total life cycle costs for each TCO alternative were calculated. All costs are in FY 93 constant budget dollars.

d. Risk Analysis

The TCO MNS defines a two component requirement. One component of the requirement is for automated tools to support operations planning and execution. The other component is for connectivity across the battlefield using tactical communications and for interoperability with other C^3 systems. These two components are interdependent, and each must be met to satisfy the TCO MNS. Since communications connectivity and interoperability will be provided through use of MCASS modules (and the Tactical Network Server (TNS)/Tactical Communications

Interface Module (TCIM)), the risk associated with satisfying the connectivity and interoperability portion of the requirement is consistent across alternatives. The risk associated with providing the required automated support for operations planning and execution varies by alternative. The total risk associated with any alternative is a function of the program risk that an individual alternative can not provide the required automated tools and the risk that MCASS modules will not provide the required connectivity and interoperability. The total risk function is defined as the maximum of the program risk and the MCASS risk.

e. Trade-Offs

The analysis team then performs a trade-off analysis between the base case and the TCO COEA alternatives by analyzing the capability rankings of each alternative in terms of operational effectiveness, operational suitability, and life cycle supportability; life cycle costs; and the risk assessment.

f. Decision Criteria

Alternative selection is based on system capability (operational effectiveness, operational suitability, and life cycle supportability); life cycle cost; and program risk.

g. Recommendations

The decision criteria will then lead to recommendations[10].

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[10] The actual recommendations of the COEA team were not officially published at the time of this writing and are outside of the scope of this thesis.

The methodology used by the COEA team is a comprehensive and effective way to evaluate alternative C^3 systems. It involves evaluating the alternatives based on their current configurations. Projected costs of adding some of the required core capabilities to the alternatives were computed and used in the evaluation, but planned upgrade paths of the alternatives were not considered in the analysis.

G. CONCLUSIONS

This chapter presented a discussion of the technology initiatives that will impact C^3 systems. The Evolutionary Acquisition concept was introduced and topics such as Non-Developmental-Items, Commercial-Off-the-Shelf products, and open architecture standards were presented. A representative sample of some current evaluation frameworks were then discussed.

It is important that the procurement environment for C^3 systems be understood by the evaluators. Important factors of the procurement environment that effect C^3 systems include; the recent increased rate of technological change, the mandated use of the Evolutionary Acquisition concept, the use of NDI and COTS products, and the evolving open architecture standards. The following conclusions can be made in regard to the environment in which C^3 system are procured:

1. That C^3 systems must capitalize on emerging technologies to remain mission capable.

2. That C^3 systems will incorporate evolutionary upgrades throughout their useful life cycle.

3. That most of these evolutionary upgrades will be composed of NDI or COTS products that adhere to "open system" standards.

The Mission-Oriented Approach, the Modular Command and Control Evaluation Structure, and the COEA team's evaluation approach represent the current state of C^3 systems evaluation. It can be concluded that none of these frameworks or methodologies specifically deal with the temporal component of C^3 systems. One of the most difficult aspects of C^3 systems is that they will continually change over time (given evolving technologies, standards and applications). No framework currently exists that specifically deals with evaluating the upgrade paths of C^3 systems.

As discussed, C^3 system procurements today can be viewed as upgrades to existing C^3 systems. Even large procurements that make sweeping changes will be incremental and evolutionary. Therefore, it is useful to explicitly embrace the evolutionary upgrade concept, and develop a framework for comparing alternative upgrade paths rather than alternative static C^3 systems. The following chapter presents such a framework.

III. A NEW FRAMEWORK

A. INTRODUCTION

1. Purpose of this Chapter

The purpose of this chapter is to present a useful framework for evaluating evolutionary upgrade paths of C^3 systems. As discussed, most C^3 system procurements will be evolutionary, and both existing and new C^3 systems will go through many changes during their useful life cycle. As emerging technologies mature, C^3 systems will be incrementally upgraded as soon as is feasible in order to remain as mission capable as possible. Procurement alternatives that capture this temporal effect are evolutionary upgrade paths.

The framework presented here is a functionally-oriented, capability-based approach intended to be a useful step by step method that produces information about alternative evolutionary upgrade paths that is useful to decision makers. The level of discussion is at a generic and sometimes abstract level so that wide applicability can be maintained.

2. The Need for Effective Evaluation

The procurement of an extensive C^3 system or an extensive upgrade to an existing C^3 system is an expensive proposition. A bad decision now could cost millions of dollars in the future, therefore, a thorough and effective evaluation framework is needed. Chapter II highlighted the major issues that effect C^3 systems and their

evaluation. It can be seen that just about all new C^3 systems will be procured over time, and will employ incremental evolutionary upgrades to keep up with technology. This temporal component of C^3 systems is a difficult aspect to evaluate. There are currently no widely accepted methods that accurately evaluate C^3 systems based on their upgrade paths. This framework will mainly focus on this temporal component and present a set of procedures for evaluating C^3 systems by viewing them as evolutionary paths toward some future goal or target system.

3. Methodology

In presenting the framework, some key terms used in the explanation of the framework will first be defined. Then, a step by step generic procedure will be presented along with recommendations on the preferred methods for accomplishing those steps. The methods developed in this framework are suited for use with virtually any C^3 system or subsystem.

B. THE FRAMEWORK

In presenting the framework, several terms are used that require definitions so that the concepts presented can be understood by the reader.

1. Definitions

a. C^3 System

A C^3 system is a collection of equipment, personnel, procedures, facilities, and communications that provide a commander the tools essential for planning, directing, and controlling operations of his assigned forces.

For the purposes of this framework, C^3 systems can be viewed as a collection of tools that provide automated support to those functions that commanders have always performed (e.g., planning, directing and controlling his forces). The focus of most acquisition related C^3 system evaluations are in the area of hardware and/or software products that provide automated support to C^3 functions that support the warfighter. Therefore, the evaluation problem that this framework is tailored to deals with those decisions regarding which hardware and/or software products to buy or invest in.

b. C^3 Functions

The C^3 functions that this framework will focus on are those functions that commanders have always performed (e.g., develop an Operations Plan or disseminate an Operations Order). This is done so that the warfighter's needs remain in focus. As discussed, C^3 systems provide automated support to C^3 functions. For the purpose of this discussion, when the automation of a function is referred to, it could either mean just automated support to that function or the full automation of that function. In order to identify the level of functions to be used in this framework, functional decompositions may be required[11].

c. Technological Capabilities

In order to provide automated support to C^3 functions, the system must afford a set of capabilities that will be called technological capabilities (e.g., word processing capability, interoperability with another system, digital mapping, etc.). Most

[11] Functional decompositions will be explained later in the chapter.

capabilities that new C^3 systems will possess are a product of some new technological advance (e.g., fiber optics, open systems standards, bubble memory, etc), therefore, they will refer to as technological capabilities. In order to provide automated support to a function, a set of technological capabilities is required. For example, to automate the production of overlays, technological capabilities such as pen/mouse user interface, digital mapping, high resolution display, iconic and symbology database, and hard copy capabilities are just a few of the technological capabilities required.

d. The Target System Functions and Capabilities

The target system is a system that provides the desired level of automated support to each of the C^3 functions within the system boundaries at some future planning horizon.

The target system functions are the set of C^3 functions that are automated in the target system, and the target system capabilities are the technological capabilities required to provide the automated support.

The target system functions and capabilities will be displayed in a function/capability table so that the relationship between them can be clearly seen. Figure 5 illustrates what this table will look like. For example, referring to Figure 5, in order to automate function F1, technological capabilities TC1 and TC3 are required.

e. Current or Base System

A current or base system is a system that is currently in use or one that could be bought today. It usually only automates a subset of the functions listed in the

FUNCTION/CAPABILITY TABLE

FUNCTIONS

TECHNOLOGICAL CAPABILITIES

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
TC1	X			X				X			X	
TC2		X			X							X
TC3	X					X				X		
TC4			X		X		X		X		X	
TC5											X	

Figure 5: Capability/Function Table

target system's function/capability table described above. In an evaluation, current or base systems are viewed as alternative base systems. These alternative base systems are those systems that can be reasonably expected to some day obtain the level of automation that is required in the target system.

f. Migratory Systems

Migratory systems are future upgraded versions of a particular base system and usually consists of the base system plus some additional technological capabilities. Several migratory systems could spawn from a base system given different evolutionary upgrade plans.

g. Viable Upgrade Path

A *viable* upgrade path is an incremental series of upgrades to a base system that will eventually lead to a fully functional target system. A *viable* path is one that is reasonable in terms of cost and risk and is agreed upon by the operational, technical, and the programmatic experts. Effective cooperation is crucial in the development of these viable upgrade paths. Figure 6 illustrates how each alternative base system could take different paths toward achieving the required target capabilities.

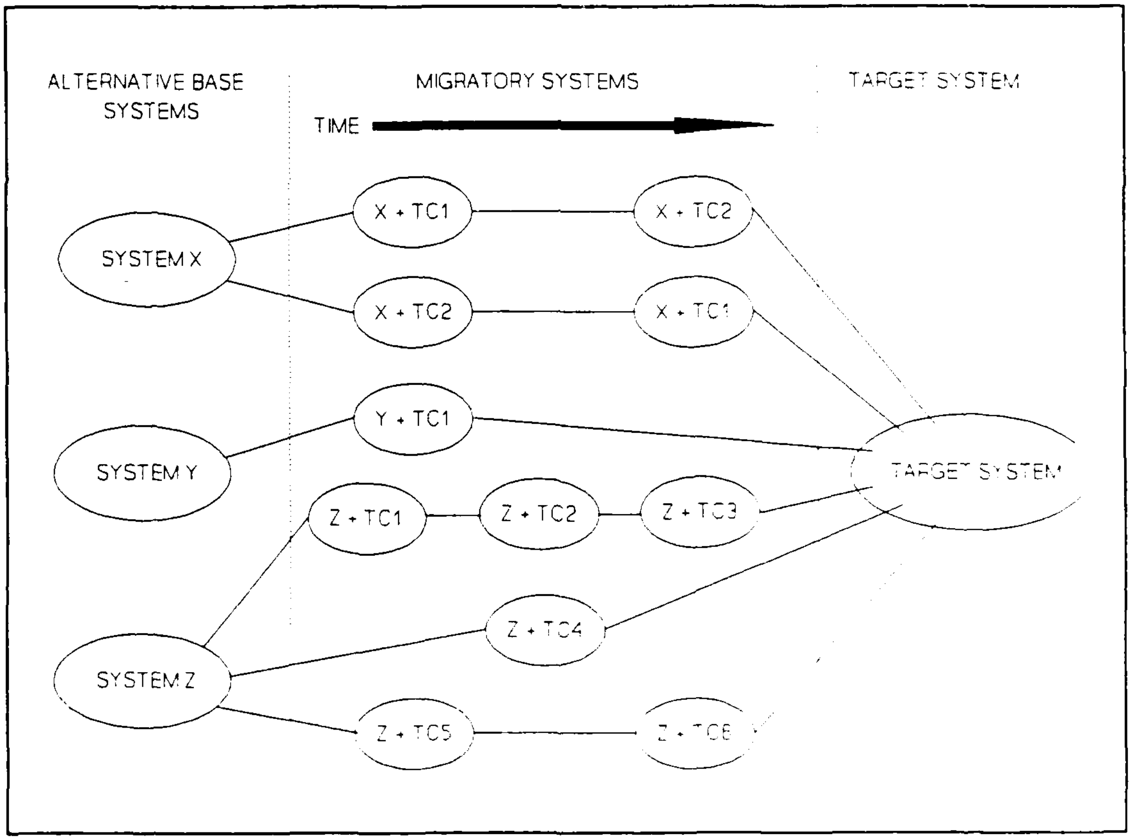

Figure 6: Illustration of Viable Paths

h. Value

The term *value* will be used to represent the benefit gained by a force when a particular function is provided the required level of automated support. This added value or benefit to the force due to the automation of a function could be measured in terms of a Measure of Force Effectiveness (MOFE)[12] or in terms of a relative importance or weight[13]. In either case, a *value* or benefit to the force, must be associated with each target system function.

i. Costs

Two types of costs are referred to in the discussion of the framework. The first type of cost focuses on procuring a particular alternative base system today. This cost should be an estimated life cycle cost of the alternative base system as it is configured today. It should include the costs associated with research, development, testing, and evaluation (RDT&E); procurement; and 15 years of operation and support (O&S)[14]. Costs associated with hardware procurement, hardware and software integration, system fielding, hardware and software maintenance, and system training and operations can be collected from government organizations, government publications, and private industry. All cost data should be normalized to the current constant budget dollars.

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[12] For example, force exchange ratio, number attackers attrited per unit time, etc.

[13] Methods for obtaining relative weights will be discussed later.

[14] The 15 year life was taken from the COEA Final Report (Draft)

The second type of cost used in the framework is the cost of adding technological capabilities to alternative base systems. The same kind of life cycle costs as discussed above should be used, but it should focus only on the costs associated with a particular technological capability and its integration into an existing system. The cost of adding a technological capability only needs to be normalized to the year in which it is projected to be added to a system. Methods for discounting these costs will be presented later.

2. The Framework

In order to evaluate alternative systems that will change over time, the ideas of a current or base system, migratory systems, and a target system help frame the problem. The current system is the system currently in use or one that could be bought today to fulfil some mission need. All systems or subsystems in place today will some day either become technologically obsolete or no longer meet the needs of the user. When the time comes to replace or upgrade that system or subsystem, decisions must be made as to how to proceed. This framework presents a method that could be useful to decision makers in making that decision. The framework contains four top level steps:

1. Define target system functions and capabilities.
2. Define all viable upgrade paths from each alternative base system to the target system; each path becomes a candidate path.
3. Develop a discounted value and a discounted cost for each candidate path.
4. Select the candidate path that maximizes value subject to a stated cost, resource, and risk constraints.

A brief summary of the steps shown in Figure 7 follows.

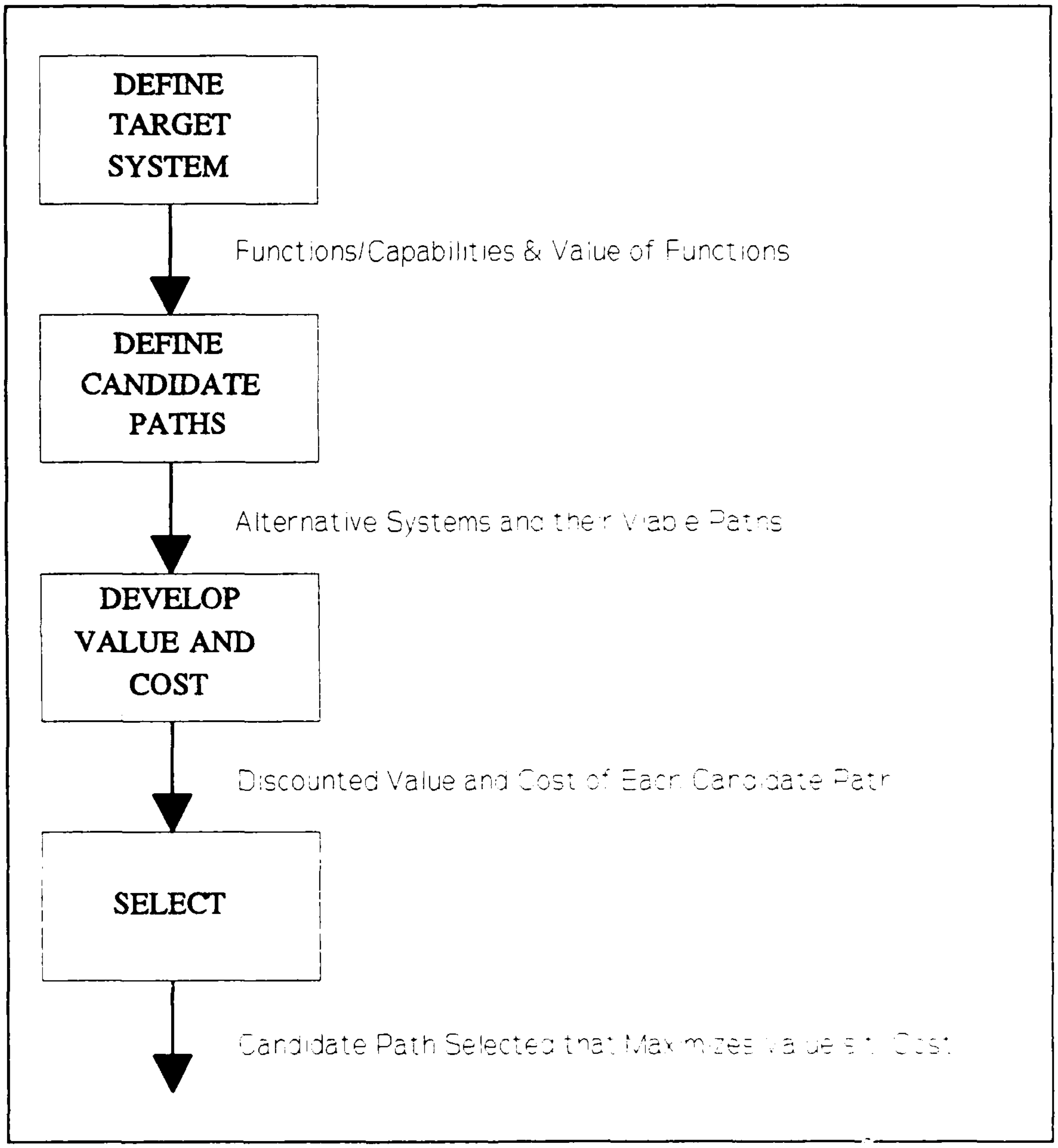


Figure 7: The Steps of the New Framework

The first step of the framework begins by defining the target system in terms of the functions it should automate and the technological capabilities required to automate

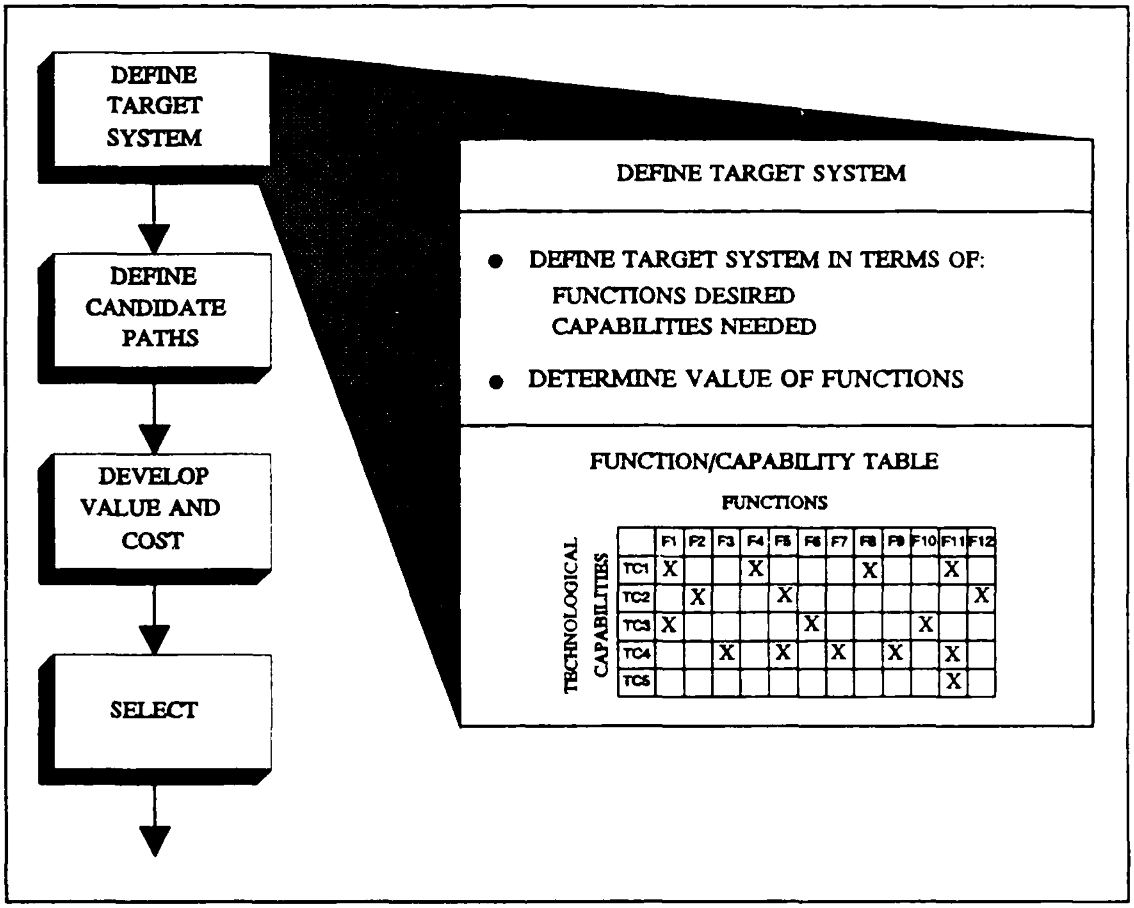
each of those functions. The value of each of those functions is then determined. The output of this step is a table highlighting the relationships between the target system's technological capabilities and the functions it must automate along with the value of each function. The second step of the framework begins by identifying all of the alternative base systems in terms of the technological capabilities they possess. All viable paths to the target system that spawn from each alternative are then determined. The output of this step is an enumeration of all viable candidate paths. The third step of the framework involves assigning functionally derived values and capability derived costs to each candidate path at discrete time intervals. These values and costs are then discounted to the present. The output of this step is a discounted value and cost associated with each candidate path. The last step of the framework involves filtering out the candidate paths that do not meet the cost constraint and then picking the candidate path that has the greatest value. This should result in the candidate path that provides the greatest value to the force given a particular cost constraint.

The above steps of the framework are expanded upon in the following sections.

a. *Define Target System Functions and Capabilities*

Figure 8 illustrates this step.

(1) Functions and Capabilities. In the acquisition world, descriptions of target systems are easily found in documents like the Mission Need Statement (MNS) and the Operational Requirements Document (ORD). These documents highlight needs,



	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
TC1	X			X				X			X	
TC2		X			X							X
TC3	X					X				X		
TC4			X		X		X		X		X	
TC5											X	

Figure 8: The New Framework - Step 1: Define Target System

requirements, and constraints for a given system. In the case of C^3 systems, from the requirements, a list of functions that require automated support can be derived. This automated support is provided via capabilities. The functions derived from the requirements are normally those that commanders and their staffs have always done (e.g., prepare an operations order and disseminate it, develop courses of action, decide on course of action, direct his forces, etc.). The functions[15] should be chosen at a level

[15] At this point, the author will assume that the functions can be automated independently, realizing that interdependence really exists.

that will allow a manageable sized list of required technological capabilities to be defined. Functional decompositions are usually required. Figure 9 illustrates what a simple generic functional decomposition looks like.

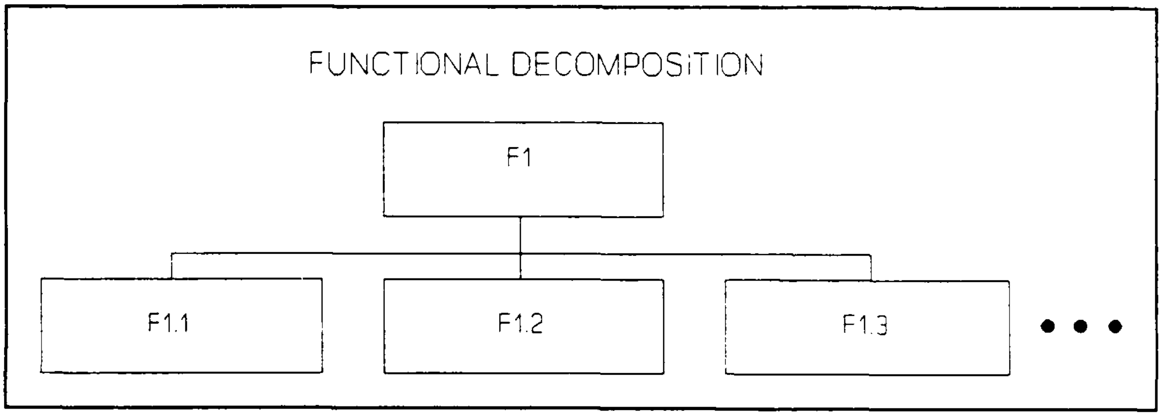


Figure 9: Example of Generic Functional Decomposition

Once the functions are identified, the technological capabilities required to provide the required automated support can be determined. Through elicitation of technical and operational experts, a list of the capabilities required to automate each function at the required level can be obtained. It should be realized here that some of the capabilities in this list may not be available yet, given the current state of technology.

After completing the above procedure, a function/capability table can be constructed that shows the relationships between the functions and the technological capabilities. Table I illustrates what this table looks like. In the column that corresponds to an operational function, an X is placed in the boxes corresponding to the rows of the technological capabilities required to automate that function. A function cannot be automated at the required level unless all the technological capabilities with an X in that function's column are provided by the system. For example, from Table I, function F1

Table I: FUNCTION/CAPABILITY TABLE

Technological Capabilities	Operational Functions			
	F1	F2	. . .	FN
TC1	X			X
TC2	X	X		X
. . .				
TCn		X		

cannot be adequately supported with the desired level of automated support unless the system possesses technological capabilities TC1 <u>and</u> TC2.

(2) Value of C^3 Functions. Once the relationship between target system functions and capabilities is known, the next part of this first step is to determine the value of each function. The goal here is to assign a value or benefit added to the overall force when a particular function is automated.

One method to accomplish this would be to design an experiment or construct a model that would allow the assessment of the effect on overall force effectiveness given that a particular function is automated. Runs of the experiment or model could be made when the function is performed without automated support and then again with the automated support[16]. The outcomes of each case could be compared and a MOFE assigned as the value of the function. This method would be done for all

[16] A typical question that could be answered is, "What effect does automating overlays have on the overall effectiveness of the force?"

of the target system functions. But, it obviously would require a substantial expenditure of time and money, both of which are usually limited.

Another method requiring less time and money would be to elicit relative values[17] or the importance of each function from experienced operational experts. The idea is to elicit from the experienced experts the relative importance to the operational force of automating each target system function. Various methods of elicitation include closed questions, open questions, brainstorming guided brainstorming, and group consensus. [Ref. 26]

Other methods such as the Analytic Hierarchy Process (AHP) or the Simple Multi-Attribute Rating Technique (SMART) can also provide tools to aid in obtaining the relative value or weight of each function to the force. [Ref. 27] These two methods structure the problem as a hierarchy which serves as a useful aid to understanding problems and fostering discussion about them. The process can reveal issues which have not previously been explicitly stated. AHP utilizes pair-wise comparisons of attributes[18], where as SMART elicited values on a 0-100 scale for each attribute. The process used by both is easy to understand and decision makers have been

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[17] The term *relative value* or *weight* has, at times, not been well received by professionals in the acquisition and operational fields because arguments among steering committee members have lasted for hours on what weights to assign. This should not be viewed as bad, in fact, this is one of the advantages of this kind of method because it forces decision makers to deal with difficult issues that may have not been explicitly stated before.

[18] Attributes, in the case of determining relative values of functions, would refer to low level functions that result from the decomposition of higher level functions.

comfortable with it[19]. Applying either of these methods would result in a list of the relative values or weights for each function. These methods emphasize the point that the value of a system (through automation of functions) is what it does for the user. This value can be estimated via the user's perception of the relative importance of the various areas in which the user benefits from the system. [Ref 28]

Table II illustrates what the results of this step should produce. In summary, the first step of this framework results in defining the target system in terms of the C^3 functions it supports and the technological capabilities required to provide automated support to those functions. Furthermore, the value of each function is

Table II: FUNCTION/CAPABILITY TABLE FOR THE TARGET SYSTEM

Technological Capabilities	Operational Functions			
	F1 V1	F2 V2	. . .	FN VN
TC1	X			X
TC2	X	X		X
. . .				
TCn		X		

determined in terms of a MOFE or by a weight or relative importance to the force. The added V1, V2, ... , VN in Table II represent the value of that particular function.

[19] Case studies can be found in Reference 27.

This table provides the information needed in subsequent steps of the framework. The next step involves defining candidate paths.

b. Define Candidate Paths

Figure 10 illustrates this step. The step of defining candidate paths requires two tasks, first the alternative base systems are determined and then the candidate paths that spawn from these alternative base systems are enumerated. The goal of this step is to come up with a list of the viable (or reasonable) candidate paths that will lead to obtaining the capabilities established in the definition of the target system functions and capabilities from step one.

This step begins by identifying the alternative base systems that will be considered in the evaluation. These alternatives should be systems that preferably already meet some of the requirements of the target system. The alternative base systems should be chosen by the experts with the target system in mind. The concept is that each chosen alternative base system could someday fulfill all the requirements of the target system by incrementally adding future technological capabilities. Initially, each alternative base system will possess a set or vector of technological capabilities, TC. Let time be discrete ($t = 1,\ldots,T$) where T is the planning horizon, then at each date t, there is a vector of technological capabilities TC_t generated by each alternative system. Each alternative system will evolve over time given that there is technological change over time (and hence automation opportunities). Several viable paths could spawn from each alternative system. Each one of these viable paths will become a candidate path and could be developed by creating a specific scenario of technological change and

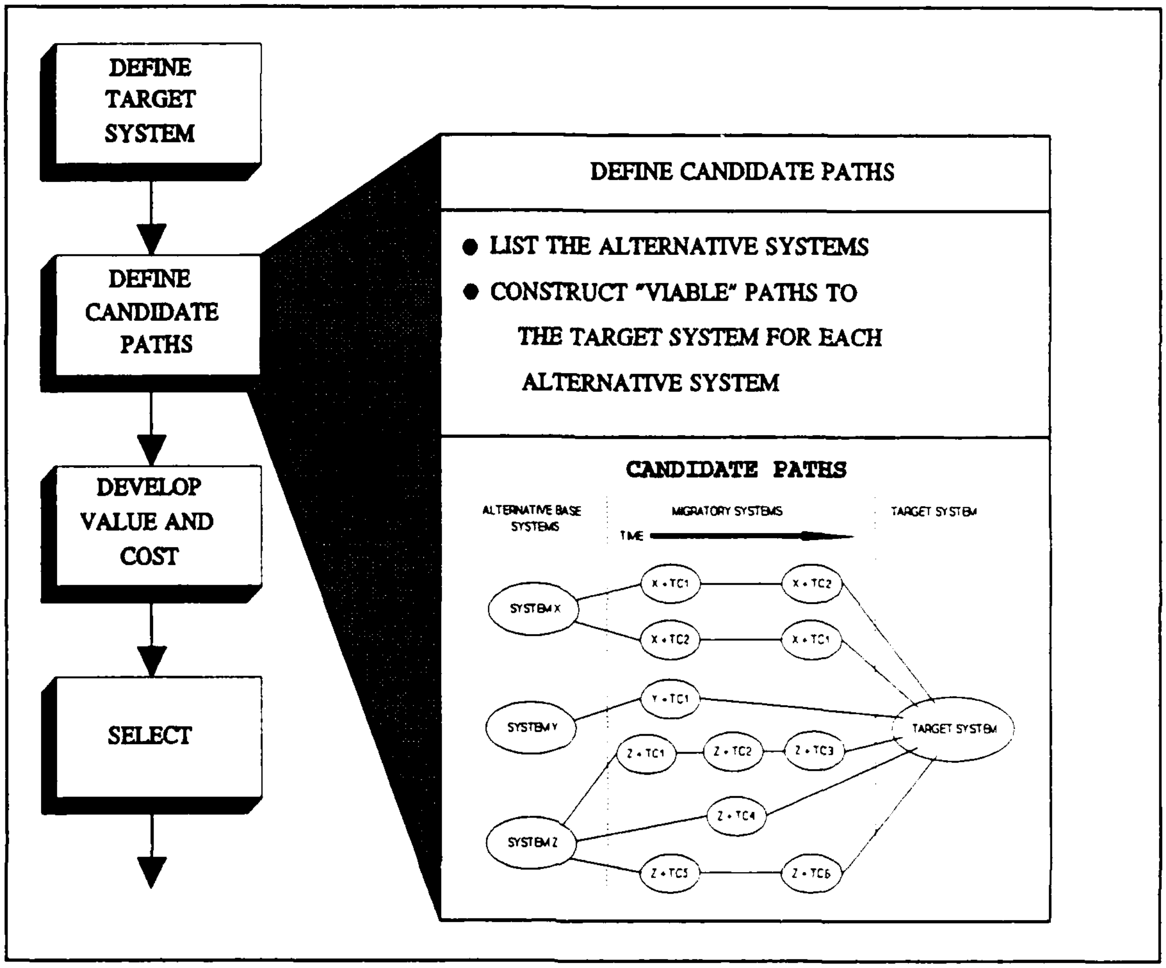

Figure 10: The New Framework - Step 2: Defining Candidate Paths

automation for its base system. Each candidate path should satisfy the current cost, resource, and risk constraints.

The Figure 11 illustrates that each particular alternative base system will migrate towards the capability of the target system by following one of several reasonable and viable paths of upgrades. Each candidate path begins at an alternative system. As technological capabilities are added, migratory systems are realized until finally the capabilities of the target system are obtained. At each date t, each candidate path has associated with it a new vector or set of technological capabilities. This list of

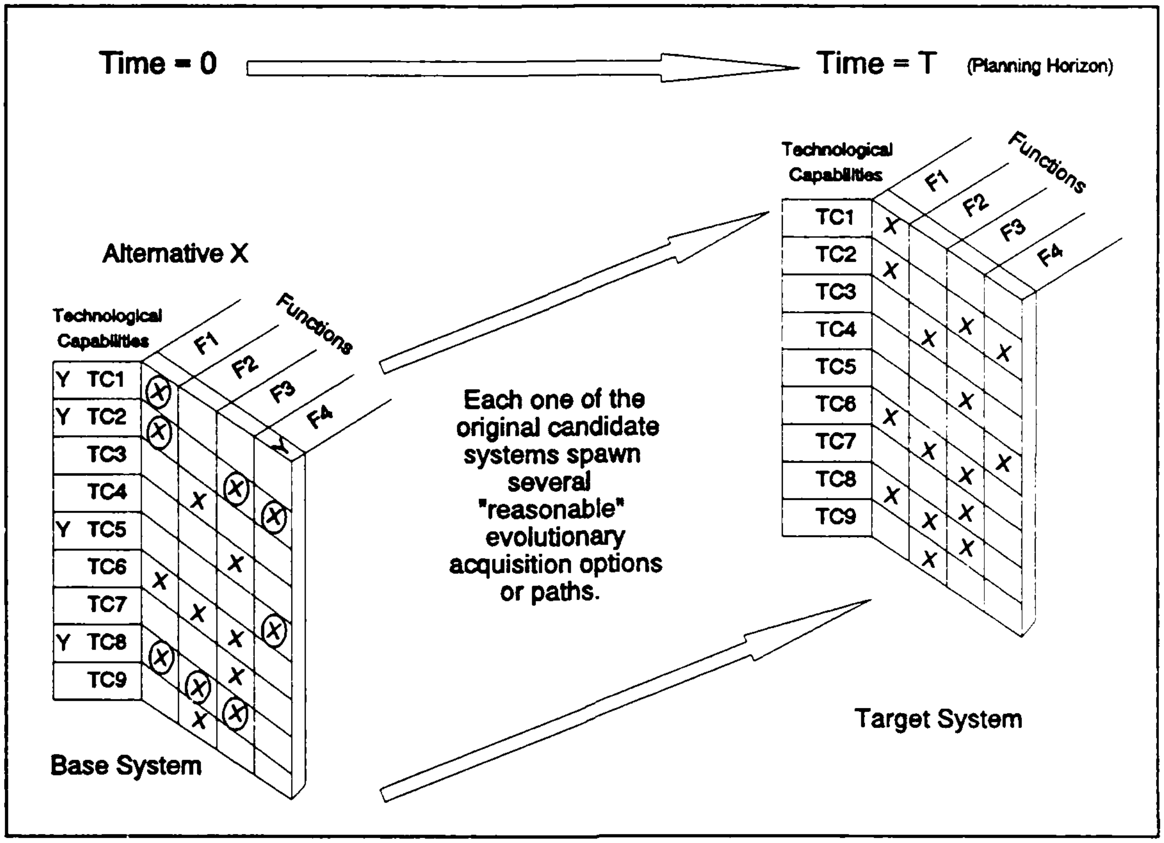

Figure 11: The Migration of Alternative Base Systems

capabilities may succeed in providing the capabilities required to provide automated support to more target system functions. Therefore, each candidate path contains a changing list of technological capabilities and a changing list of functions that it can provide the required automated support to. The next step of the framework involves determining the overall value and cost of each candidate path.

c. Get Values and Costs

Figure 12 illustrates this step. The goal of this step is to derive a single overall discounted value and a single overall discounted cost for each candidate path

constructed in step two of the framework. Methods for determining the discounted values and costs will be presented in the following sections.

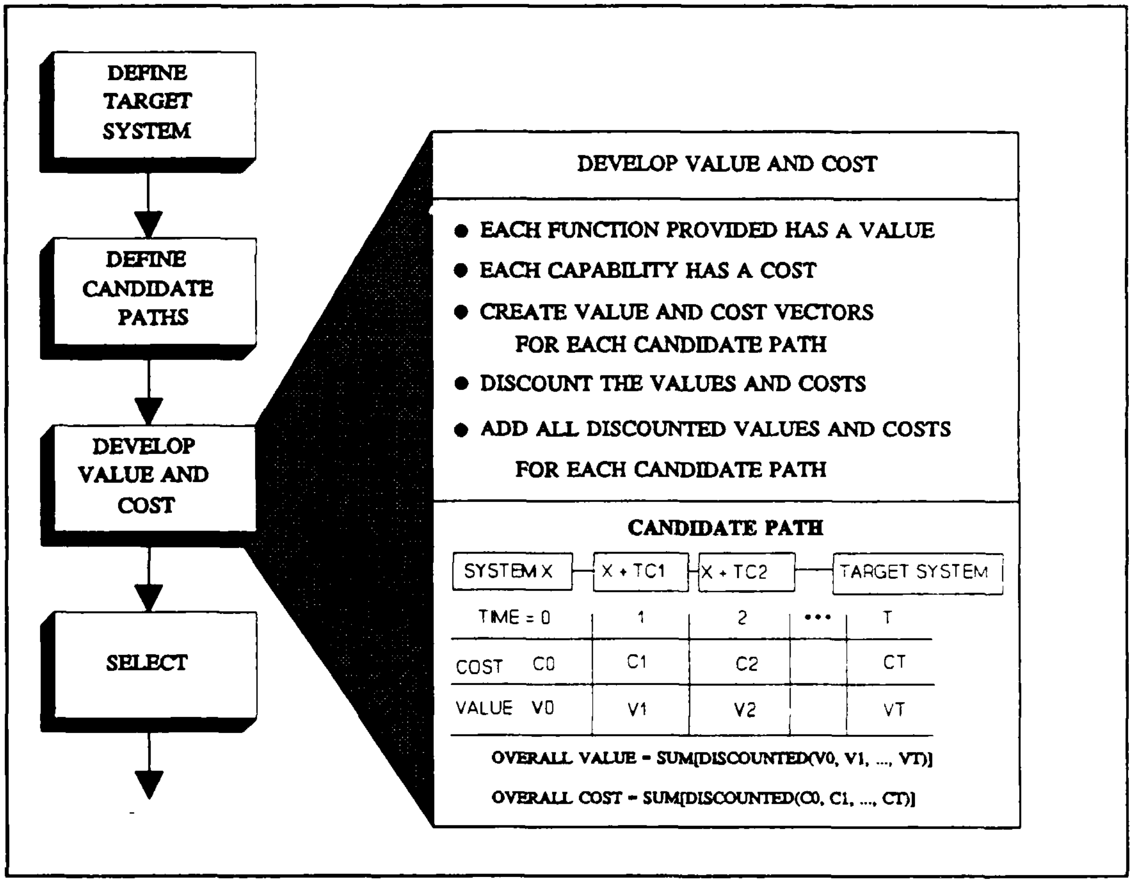

Figure 12: The New Framework - Step 3: Develop Value and Cost

(1) Value. Since the value of each function defined in the target system is now know from step one, the overall value of any candidate path depends on the functions it succeeds in automating and when they are automated. Any set or vector of technological capabilities, TC, can be easily assigned a value by adding the values of the functions that the set of capabilities automates. Since each candidate path is actually a time series of TC vectors, at each time step there is a TC_t (vector of technological capabilities at time t). Each successive TC_t vector of a candidate path may provide the

capability to automate additional functions by the addition of more technological capabilities. So each candidate path can be viewed as a time series of upgrades (additional technological capabilities added) that incrementally automate additional functions until all the functions of the target system are given the required level of automation support (from the definition of the target system in step one).

If each candidate path simply receives the value of a function when it succeeds in automating it, all paths will receive the same value since all candidate

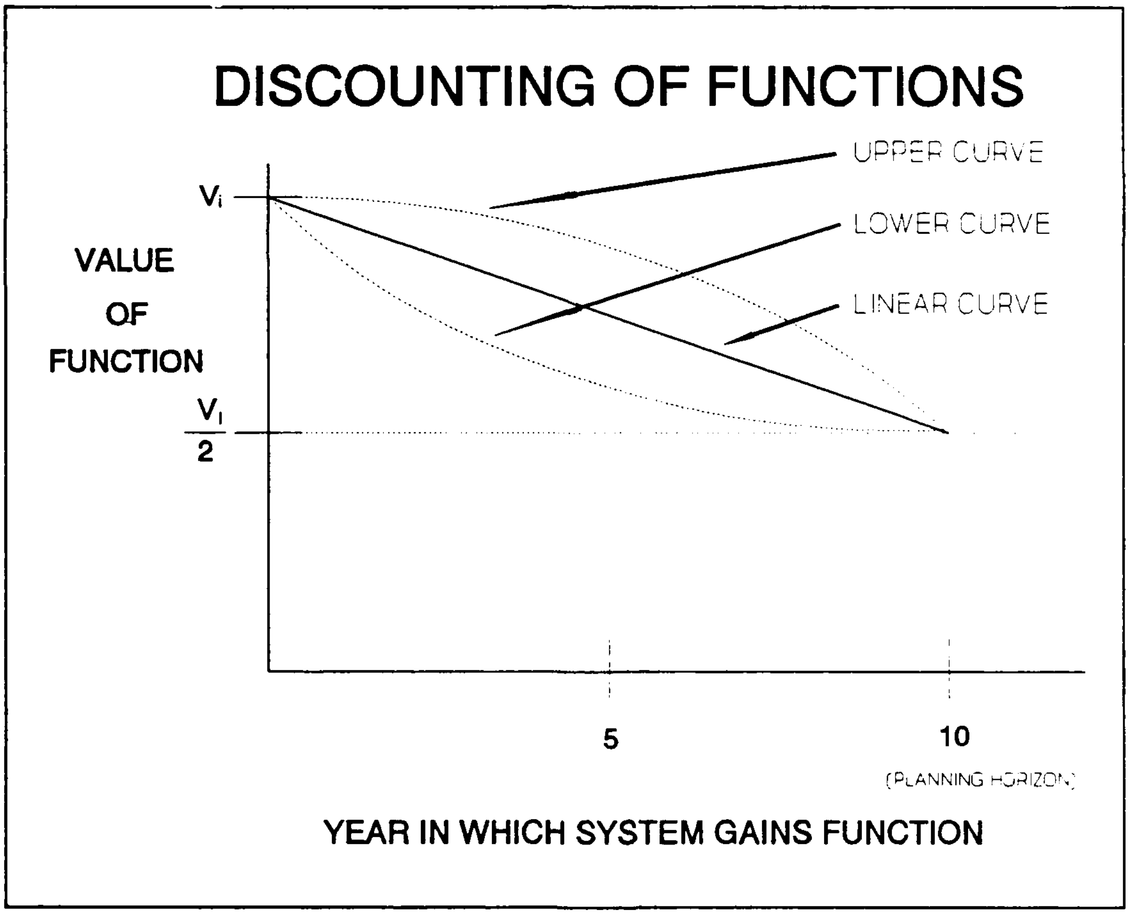

Figure 13: A Way to Discount the Value of a Function

paths will eventually automate all of the target system functions. Clearly, it is more useful to the warfighter to provide automated support today rather that several years in the future. Measures used to compare paths should reflect this difference. Therefore, in order to make this a meaningful measure, a method of discounting the value of functions must be used. In order to develop a discounted value for the candidate paths, a value versus time curve for each function is needed. It is generally agreed that the sooner a system can automate a particular function, the more valuable that system will be to the user in terms of that function. That is, a candidate path that automates a particular function earlier than another should receive more value for automating that function sooner. Therefore, for each function, a kind of "utility" curve could be developed like that in Figure 13[20]. The lower curve could be used for functions that are more critical to the users. That is, if two candidate paths are being compared, the path that automates a function (utilizing the lower curve for its discounting) the soonest, will receive a far greater value than a path that automated the function later. Where as, if the upper curve was used, the difference in value between two paths would be less. For ease of calculations, the simplest case would be that at the present time ($t = 0$), the full value of a function is given if the vector of technological capabilities, TC_0, present in the alternative base system for a candidate path has all the capabilities required to automate that function. If, on the other hand, the function is not automated until the planning horizon, say ten years ($t = 10$), by the vector TC_{10}, some residual fraction

[20] A thorough discussion of utility theory and its relationship to decisions under risk is contained in Chapter 11 of Reference 29.

(one-half is chosen for the illustration) of the value to the force of automating that function would be given to the candidate path.

How this "utility curve" of the value of the function in Figure 13 behaves between the present time and the planning horizon is a function of the temporal importance or the time criticality of automating that function as discussed above.

The discounted values, denoted DV, for each function are derived from each function's utility curve and are a function of the time the system received the capability to automate that function. The following equation would be used to calculate the discounted value of a function if the linear relation in Figure 13 was chosen:

$$DV_i = V_i - t\left(\frac{V_i}{20}\right) \tag{1}$$

Where DV_i is the discounted value of the i^{th} function, V_i is the value of the i^{th} function at $t = 0$, and t is the year or time period that the candidate path successfully automates the function i.

The overall discounted value, ODV, of a particular candidate path would then be the sum of the discounted values of each function[21]. To find the overall discounted value of the candidate path, the individual discounted values of each function are simply added. The following equation will be used:

[21] Still assuming that independence exists between functions.

$$ODV=\sum_{i=1}^{N} DV_i \tag{2}$$

Where ODV is the overall discounted value of the candidate path, i is a counter for the individual functions, N is the total number of functions, and DV_i is the discounted value of the i^{th} function.

This concept of functionally derived values can provide valuable insight into prioritizing the more important technological capabilities for future acquisition decisions. Candidate paths that receive relatively high values will undoubtedly benefit the user more than one with a lower value because the more important functions are automated sooner.

(2) Cost. Costs used in this framework are derived from capabilities and are those discussed in Section 2, Paragraph i. They consist of the cost of the alternate base system if bought today and the cost of adding a particular technological capability in the future to a given base system. Costs of adding a particular technological capability may be different for each alternative base system because each system may require different combinations of hardware and/or software to provide the required level of automation depending on the current configuration of the base system. As discussed earlier, the costs should include the costs associated with research, development, testing, and evaluation (RDT&E); procurement; and 15 years of operation and support (O&S)[22]. Costs associated with hardware procurement, hardware and software integration, system fielding, hardware and software maintenance, and system training and operations can be

[22] The 15 year O&S time frame was used in the COEA Final Report (Draft). [Ref. 8]

collected from government organizations, government publications, and private industry. The cost of the alternative base system should be normalized to the current constant budget dollars, but the cost of adding the technological capabilities should be normalized to the year in which they are added to a candidate path.

Discounted costs of adding technological capabilities are computed using the standard discounting function:

$$DC_j = \left[\frac{1}{(1+r)^y}\right] C_j \tag{3}$$

Where DC_j is the discounted cost of adding the j^{th} technological capability, r is the discounting factor or interest rate, y is the year or time period, and C_j is the cost of adding the j^{th} technological capability to the system.

To calculate the overall discounted cost of the candidate path, the initial cost of the alternative base system is added to the discounted cost of each technological capability that is added to the candidate path. The following equation is used to compute the overall discounted cost of a candidate path:

$$ODC = IC + \sum_{j=0}^{M} DC_j \tag{4}$$

Where ODC is the overall discounted cost of a candidate path, IC_j is the initial cost of buying the alternative base system, M is the total number of technological capabilities that are added to a candidate path, and DC_j is the discounted cost of adding the j^{th} technological capability. Figure 14 illustrates these calculations.

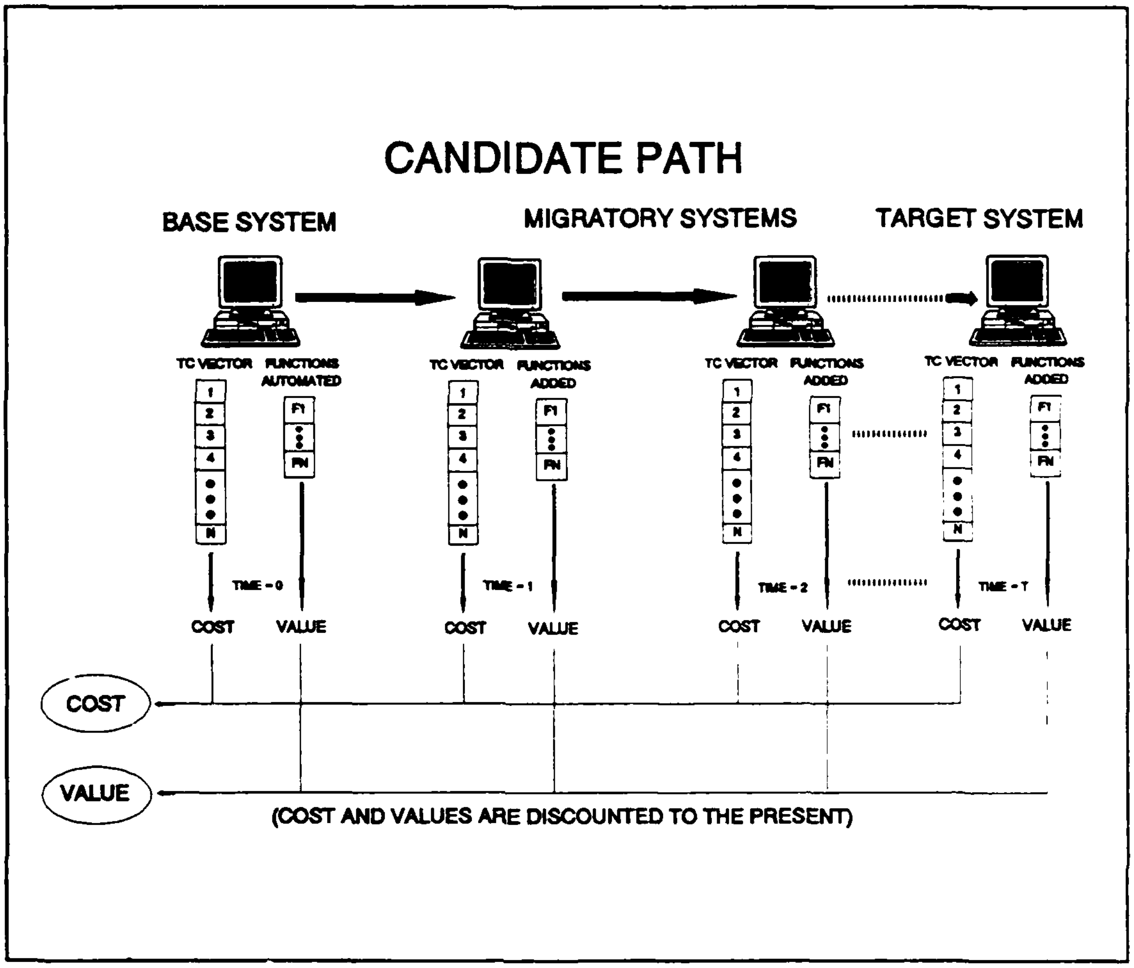

Figure 14: The Discounting of Values and Costs

The procedure for finding the overall discounted value and cost of a candidate path is straight forward. The first step involves determining when (or at which time periods) the candidate path will succeed in automating the functions of the target system. The second step requires the use of Equation (1) to compute the discounted value of each of the functions. The third step uses Equation (3) to calculate the discounted costs of the technological capabilities that are added to the system. The fourth and fifth steps use Equations (2) and (4) to compute the overall discounted value and cost of the candidate path.

The output of the above calculations is a single overall discounted value and a single overall discounted cost for each candidate path. The next step discusses how to select the best candidate path given this data.

d. Select Candidate Path

Figure 15 illustrates the final step. The above procedures will result in a list of the discounted values and costs for each candidate path. A simple, but common problem statement is to maximize value subject to cost, resource, and risk constraints. The rule or problem is stated as:

Maximize: **Value**

Subject to:
- **Cost**
- **Resource**
- **Risk**

This would result in the candidate path that provides the user with the best possible benefit within the established cost, resource, and risk thresholds. The method for selecting the best candidate path under this rule is to disregard the candidate paths that do not meet one or more of the constraints. Then select from the remaining candidate paths the one with the highest value.

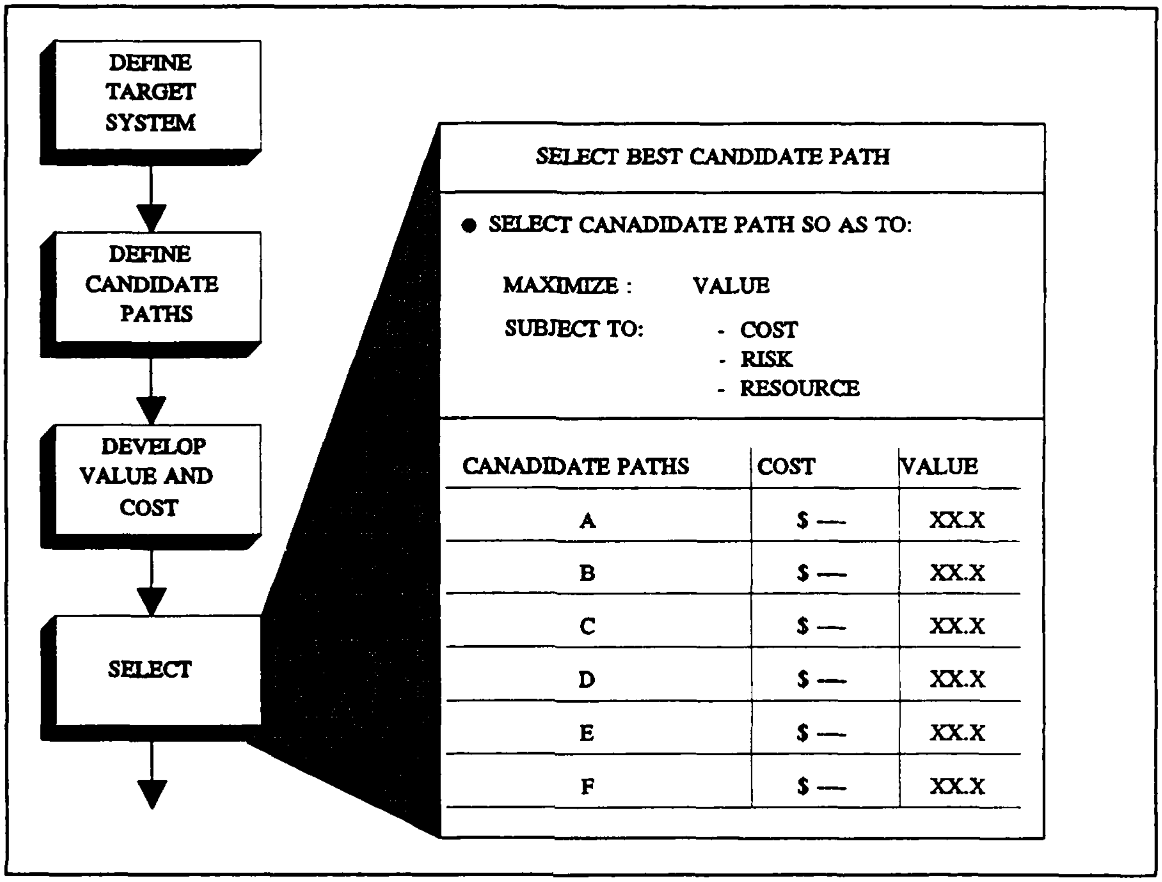

Figure 15: The New Framework - Step 4: Select Best Candidate Path

3. Conclusions

In the above discussion, a framework for evaluating alternative evolutionary upgrade paths was developed. Methods for defining a target system, developing candidate paths, and assigning values and costs to those paths have been presented. These values and costs can then be compared given a set of decision criteria and the "best" system with its associated upgrade path can be selected. It would then be up to the decision makers to consider any further issues before reaching their final decision.

These kinds of decisions may be made many times (for each upgrade procurement). For each evaluation, some or all of the process will be repeated; if the functions to be supported have changed (which may be infrequent), the target system functions and capabilities could be modified, giving a new set of functions with associated values. In either case, technological advances will make new capabilities available, giving new sets of candidate paths with their associated discounted values and costs.

The overall goal of evaluating alternatives is to pick the "best" alternative. For this framework, the "best" alternative is the system that provides us the best path (series of upgrades over time) to some target system by maximizing the value of the system (and system path) subject to cost, resource, and risk constraints. The value and cost of a candidate path that spawns from a base system will be measured in terms of the discounted cost and the discounted value of each upgrade path. This framework will help the decision makers by providing insightful and valuable information on the upgrade paths of the decision alternatives.

4. Application of the Framework

The above presentation was at a rather general and abstract level. The following chapter will provide a more concrete illustration of how this framework can be used to evaluate a real C^3 system, the USMC's current TCO system.

VI. AN ILLUSTRATED EXAMPLE

A. INTRODUCTION

1. Purpose of this Chapter

The purpose of this chapter is to provide an illustration of the framework described in Chapter III. The illustration will focus on the Marine Corp's TCO system described in Chapter I. The illustration should clarify how the methods discussed in the previous chapter can be applied. Values and costs used in the illustration are not actual values and are included in order to facilitate the illustration. Furthermore, only a small sample of the functions and technological capabilities of TCO will be used in this illustration.

2. The Problem

The problem associated with the Marine Corp's Tactical Combat Operations System is a common one. Most new military C^3 systems will require a Cost and Operational Effectiveness Analysis (COEA) to be done on the chosen alternative base systems. In the case of TCO, several alternative base systems were selected[23]. The TCO COEA team is currently performing an analysis on the alternatives and will recommend to the decision makers the alternative that best meets the needs of the Marine Corp's TCO system in June 1993.

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[23] See Chapter I for the list of alternatives.

While it is agreed that no system can currently satisfy all of the TCO requirements, the actual goal should be to pick the system that offers the "best" path toward achieving the Target TCO system requirements. The actual requirements for TCO were derived from the approved Mission Need Stateme .t MNS) dated 16 June 1992 and are divided into core requirements and follow-on requ.:ements. [Ref. 8]

The following sections present the illustration.

B. THE ILLUSTRATION

1. Define Target System Functions and Capabilities

The first step of the framework begins by defining the target TCO system functions and capabilities. The functions are those it must automate and the technological capabilities are those required to provide automated support to each of the functions. Values of each of the functions to the force are then estimated. The output of this step is a table highlighting the relationship between the target system's technological capabilities and the functions it automates.

The Target TCO System can be defined by using the core and follow-on requirements found in the MNS. From this document a list of functions requiring automation is derived. To obtain functions that are at the appropriate level of complexity for use in this framework, functional decompositions are required. The functions of the target system should be at a level that would allow the list of technological capabilities required to automate that function to be a list that is manageable in size. To illustrate this point, let us begin with the relatively high level function of producing an operations

order. This function could be decomposed into many lower level functions. For the purposes of this illustration only a subset of these lower level functions are used. Figure 16 illustrates the simple functional decomposition required for this example. The functions chosen for this illustration are the mapping function, the overlay production function, and the information exchange function and can be seen in Figure 16.

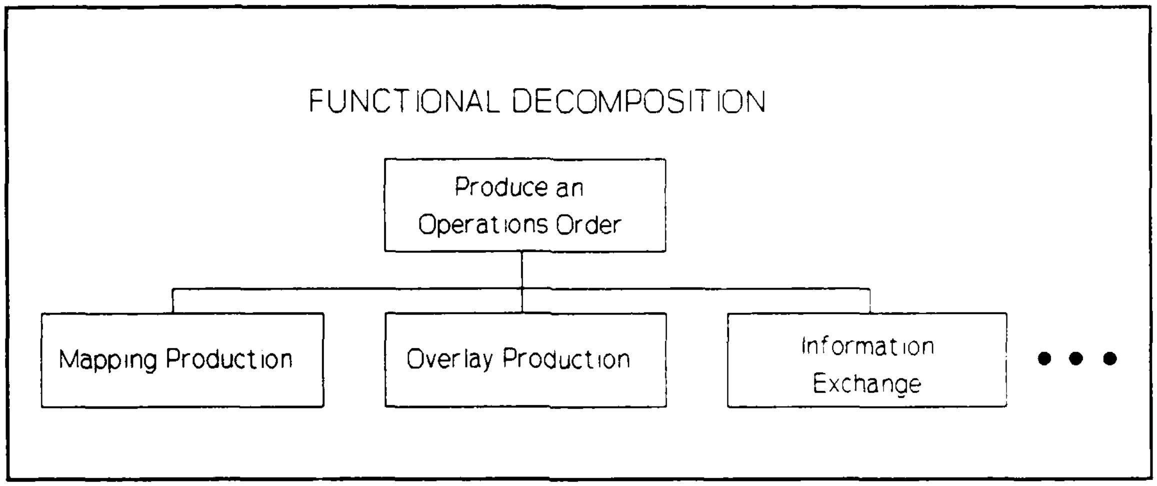

Figure 16: Example of the Functional Decomposition Performed for Step 1

Past, present, and future commanders and their staffs have performed, now perform, and probably will always perform these functions. The level of automated support will change as technologies mature. The requirement given in the MNS for TCO calls for these functions to be automated. The following table shows the relationship between these functions and their associated required technological capabilities. For the purpose of this illustration, the technological capabilities listed in the table are actually only a representative subset of the needed capabilities to provide automated support the these functions. The table in Figure 17 will serve as the definition of our TCO Target System functions and capabilities.

FUNCTION/CAPABILITY TABLE FOR THE TARGET TCO SYSTEM

TECHNOLOGICAL CAPABILITIES	FUNCTIONS		
	Automate Mapping	Automate Overlays	Automate Info Exchange
Selectable level of Map Detail	X	X	
Zoom-In/Zoom-Out Capability	X	X	
DMA Product Compatibility	X		X
Scanned Map Capability	X		
3-D Map Capability	X		
Generate Overlays		X	
Disseminate Overlays		X	X
3-D Overlay Capability		X	
Large Color Print Capability		X	
Large Screen Display		X	
LAN Connectivity			X
Single Channel Radio Connectivity			X
Switched Backbone Connectivity			X

X -- Denotes that the Technological Capability is required to automate that Column s Function

Figure 17: Function/Capability Table for the TCO Target System

Note that even some of the technological capabilities are quite complicated. Further definitions of the technological capabilities are needed in order to determine exactly when a particular system obtains that technological capability in the future. For example, the technological capability of DMA product compatibility requires that the system has the capability to build, store, retrieve, display, and transmit a digital map from either a raster or vector DMA map source. [Ref. 8]

The next part of this step involves assigning values to the functions in the form of MOFEs or relative weights. As discussed in Chapter III, a method needs to devised for obtaining a value for each function. For the purpose of the illustration the elicitation method will be simulated by assigning an equal weight of one (1) to each

function. This serves to make further calculations simpler and is a viable option for the evaluators if time and resources limit the construction of a model or an exercise to derive MOFEs or the taking of a survey. Also, if the evaluators feel that relative weights won't be acceptable to the decision makers, they have the opportunity to assign their own weights or assign equal weights to each function.

Now that the Target System functions and capabilities are defined and a value of one (1) given to each of the functions, it is time to proceed to the next step of the framework.

2. Define Candidate Paths

The second step of the framework involves identifying all of the alternative base systems in terms of the technological capabilities they possess. All viable paths to the target system functions and capabilities that spawn from each alternative are then determined. The output of this step is an enumeration of all candidate paths.

With only the draft final COEA report available at the time of this writing, the alternative systems listed in Chapter I may not be all that the USMC will consider. For purposes of this illustration, candidate paths will only be enumerated for two of the alternative systems, the Naval Tactical Control System-Afloat (NTCS-A) and the Intelligence Analysis System (IAS). These two systems will become the alternative base systems for TCO.

Neither alternative obtains all of the technological capabilities required to automate the three target system functions, but each currently possesses a subset of them as shown in Figures 18 and 19. Figure 18 contains a function/capability table for the

FUNCTION/CAPABILITY TABLE FOR NTCS-A BASE SYSTEM

TECHNOLOGICAL CAPABILITIES	FUNCTIONS		
	Automate Mapping	Automate Overlays	Automate Info Exchange
Selectable level of Map Detail	X	X	
Zoom-In/Zoom-Out Capability	X	X	
DMA Product Compatibility	X		X
Scanned Map Capability	X		
3-D Map Capability	X		
Generate Overlays		X	
Disseminate Overlays		X	X
3-D Overlay Capability		X	
Large Color Print Capability		X	
Large Screen Display		X	
LAN Connectivity			X
Single Channel Radio Connectivity			X
Switched Backbone Connectivity			X

X -- Denotes that the Technological Capability is required to automate that Column's Function

X Denotes that the System possesses this Technological Capability

Figure 18: Function/Capability Table for the NTCS-A

NTCS-A alternative base system and Figure 19 contains the function/capability table for the IAS alternative base system. The tables show what technological capabilities the two alternative base systems have today.

The next step involves selecting the viable paths that spawn from each alternative that will eventually fulfill the target system's requirements. In the case of NTCS-A, to provide the required automated support to the mapping function, scanned maps and three-dimensional maps technological capabilities are required. To meet the automation of overlays requirement, a three-dimensional overlay capability is required and to automate the information exchange function, LAN connectivity and Switched

FUNCTION/CAPABILITY TABLE FOR IAS BASE SYSTEM

TECHNOLOGICAL CAPABILITIES	FUNCTIONS		
	Automate Mapping	Automate Overlays	Automate Info Exchange
Selectable level of Map Detail	X	X	
Zoom-In/Zoom-Out Capability	X	X	
DMA Product Compatibility	X		X
Scanned Map Capability	X		
3-D Map Capability	X		
Generate Overlays		X	
Disseminate Overlays		X	X
3-D Overlay Capability		X	
Large Color Print Capability		X	
Large Screen Display		X	
LAN Connectivity			X
Single Channel Radio Connectivity			X
Switched Backbone Connectivity			X

X -- Denotes that the Technological Capability is required to automate that Column s Function

X Denotes that the System possesses this Technological Capability

Figure 19: Function/Capability Table for the Intelligence Analysis System

Backbone connectivity is required. Similarly, in the case of IAS, to provide the required automated support to the mapping function, scanned maps and three-dimensional maps technological capabilities are required. To meet the automation of overlays requirement, a three-dimensional overlay capability and large screen display capability is required and to automate the information exchange function, LAN connectivity and Switched Backbone connectivity is required.

Through cooperation of technical, operational, and programmatic experts, viable timed patterns of adding these capabilities can be developed. The table in Figure 20 summarizes the viable paths that are used in this illustration. Only two paths for each

THE VIABLE PATHS

TECHNOLOGICAL CAPABILITIES	ALTERNATIVE BASE SYSTEMS			
	NTCS - A		IAS	
	PATH 1	PATH 2	PATH 3	PATH 4
Scanned Map Capability	YEAR 1	YEAR 2	YEAR 1	YEAR 2
3-D Map Capability	YEAR 2	YEAR 4	YEAR 2	YEAR 3
3-D Overlay Capability	YEAR 3	YEAR 4	YEAR 3	YEAR 4
Large Screen Display	N/A	N/A	YEAR 4	YEAR 5
LAN Connectivity	YEAR 4	YEAR 1	YEAR 4	YEAR 1
Switched Backbone Connectivity	YEAR 5	YEAR 5	YEAR 5	YEAR 1

NOTE: Contents of table denotes what year a particular path will obtain that Technological Capability

Figure 20: The Viable Paths

alternative base system has been chosen for simplicity, although there may actually be many viable paths. The four paths will become the Candidate Paths for the evaluation. The table in Figure 20 indicates for each alternative base system's path, what year a particular technological capability will be added to the base system. As discussed in Chapter III, selection of these candidate paths require experts in many disciplines to agree on what can be considered viable upgrade paths. One method would be to charter an independent agency to perform this task. With the candidate paths determined, the evaluator can move on to the next step of getting the discounted values and costs of each candidate path.

3. Get Values and Costs

The third step of the framework involves assigning functionally derived values and capability derived costs to each candidate path at discrete time intervals. These values and costs are then discounted to present values and costs and added

together. The output of this step is a single discounted value and a single discounted cost associated with each candidate path.

Figure 21 graphically illustrates what each candidate path looks like. For simplicity, only a time span of five years is chosen. It is clear that each candidate path is simply a timed insertion of technological capabilities.

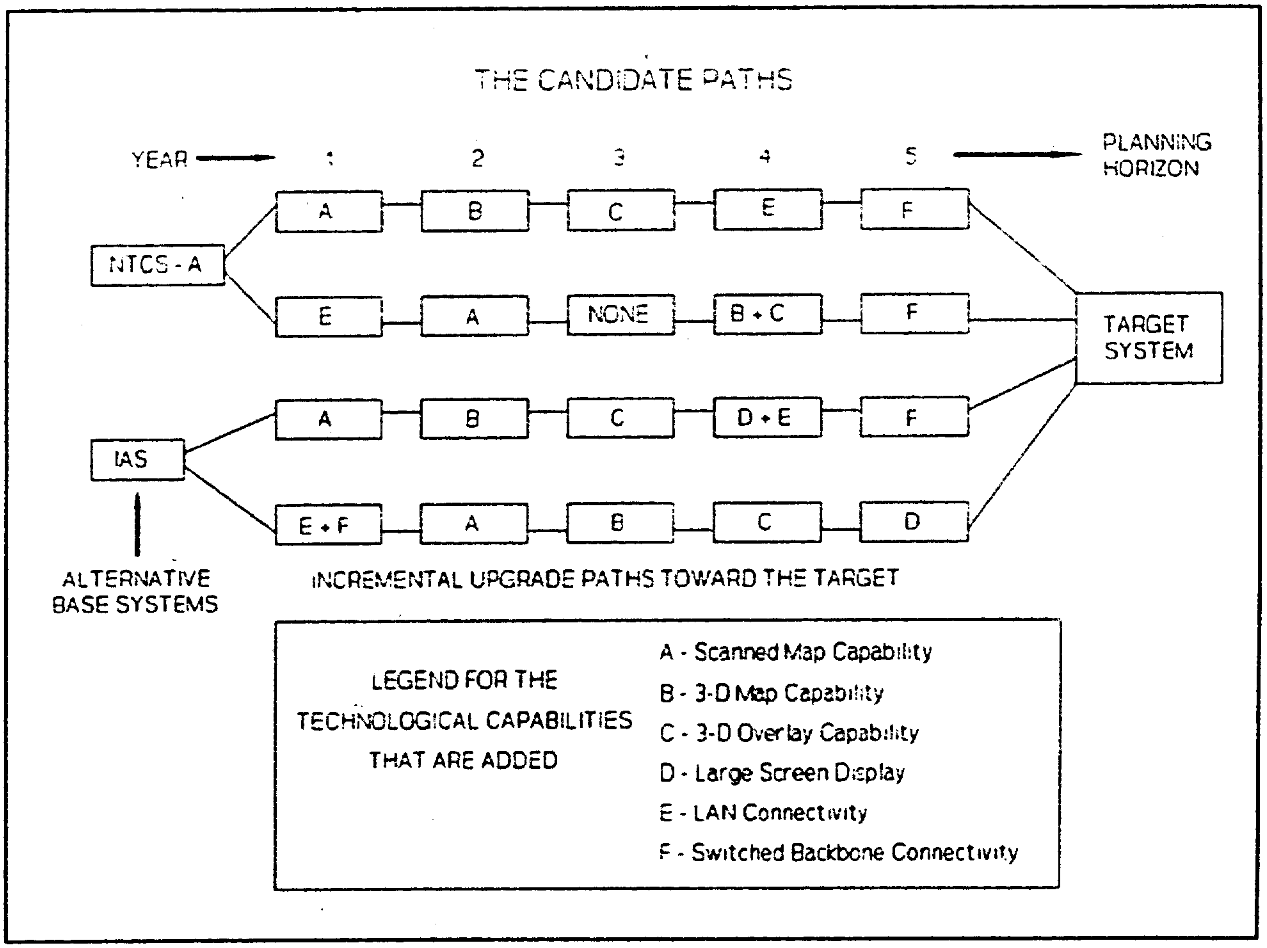

Figure 21: The Viable Candidate Paths

As technological capabilities are added, the system will periodically obtain enough technological capabilities to provide the required level of automated support to one or more of the target system functions. Each candidate path will eventually succeed in

reaching the required level of automation stated in the definition of the target system functions and capabilities.

The overall discounted value of a candidate path is the sum of the discounted values of each function. The discounted value of a function depends on when (e.g., what year) that function is successfully automated in a candidate path. A simple method for discounting the value of a function is illustrated in Figure 22. The graph shows the relationship between the value of a function and the year in which it is added to the candidate path. If the system obtains a function today, it receives the full value of that function (one). Likewise, if the function is not automated until say 10 years from now, it only receives half[24] the determined value of the function (one-half). How the graph behaves in between the present and the planning horizon depends on the time utility or temporal importance the users place on receiving a particular function[25]. Functions that are added sooner will contribute more value to the overall value of a candidate path than if they were added later.

To compute the discounted value of the functions, the linear relationship in Figure 22 is used for simplicity. This yields the following equation for determining the discounted value of a function:

[24] The residual value of one-half was arbitrarily chosen by the authors. Evaluators should feel free to pick an appropriate residual or terminal value of obtaining a particular function.

[25] A thorough discussion on Utility theory can be found on page 258 of Reference 29.

$$DV_i = 1 - t\left(\frac{1}{20}\right) \qquad (5)$$

Where DV_i is the discounted value of the i^{th} function, 1 is the value of each function at $t = 0$, and t is the year or time period that the candidate path successfully automates the function i.

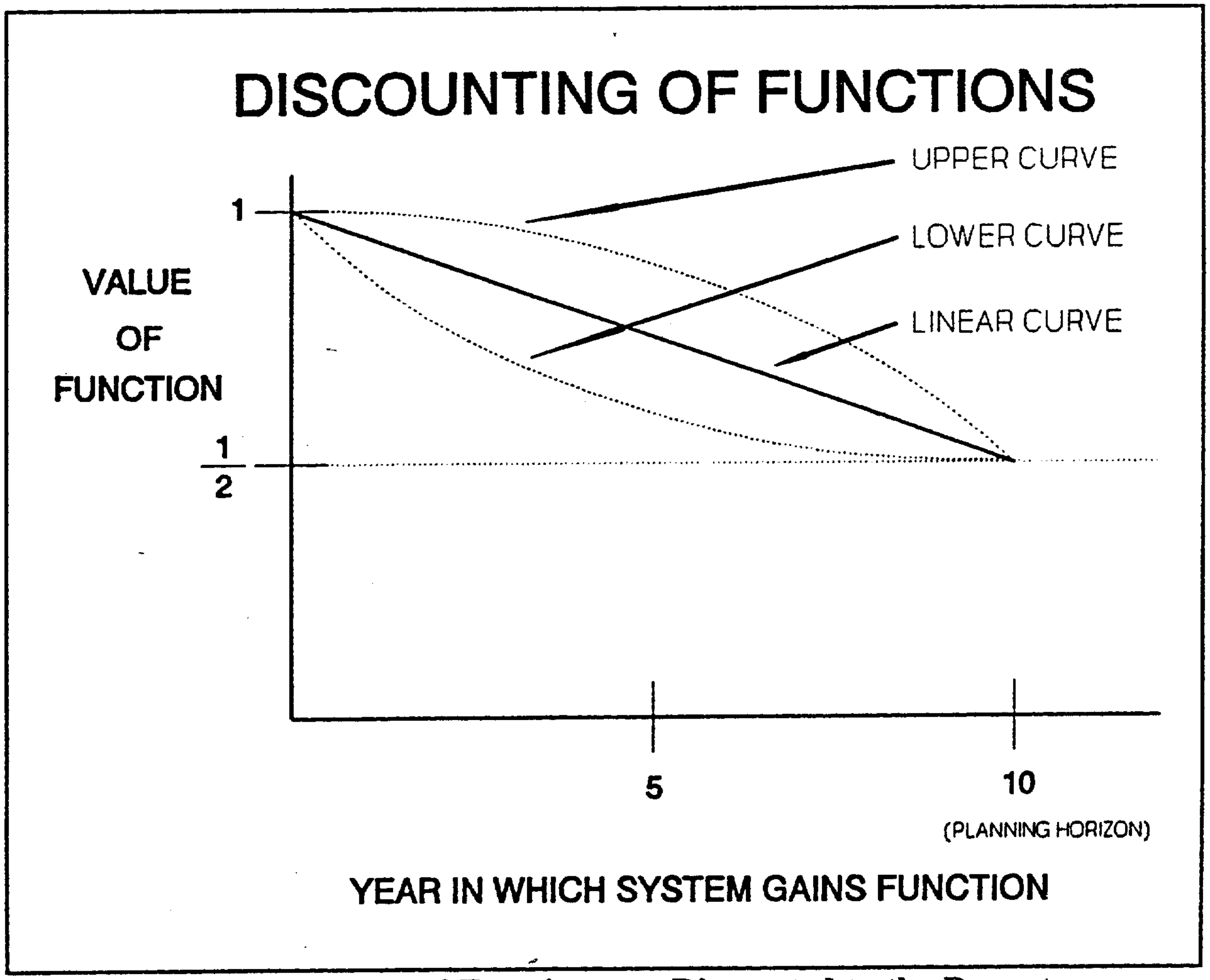

Figure 22: How the Value of Functions are Discounted to the Present

To find the overall discounted value of the candidate path, the individual discounted values of each function are simply added. The following equation will be used:

$$ODV=\sum_{i=1}^{N} DV_i \tag{6}$$

Where ODV is the overall discounted value of the candidate path, i is a counter for the individual functions, N is the total number of functions, and DV_i is the discounted value of the i^{th} function.

Costs of the candidate paths that the framework uses are the cost of the alternate base system if bought today and the cost of adding a particular technological capability to given base system. Costs of adding a particular technological capability may be different for each alternative base system because each system may require different combinations of hardware and/or software to provide the required level of automation depending on the current configuration of a given base system. Figure 23 shows the estimated costs of adding the needed technological capabilities to the two alternative base systems chosen.

Discounted costs of adding technological capabilities are computed using the standard discounting function:

COST OF PROVIDING ADDITIONAL TECHNOLOGICAL CAPABILITIES		
TECHNOLOGICAL CAPABILITIES	ALTERNATIVE BASE SYSTEMS	
	NTCS - A	IAS
Scanned Map Capability	$ 400,000	$ 400,000
3-D Map Capability	$ 207,000	$ 207,000
3-D Overlay Capability	$ 207,000	$ 207,000
Large Screen Display	N/A	$ 355,000
LAN Connectivity	$ 100,000	$ 60,000
Switched Backbone Connectivity	$ 473,000	$ 120,000

NOTE: Contents of table denotes cost of adding the Technological Capability to a particular Base System
Costs were estimated using data from the COEA Final Report (Draft), Appendix K (Costs)

Figure 23: Technological Capabilities and their Costs

$$DC_j = \left[\frac{1}{(1+r)^y}\right] C_j \qquad (7)$$

Where DC_j is the discounted cost of adding the j^{th} technological capability, r is the discounting factor or interest rate, y is the year or time period, and C_j is the cost of adding the j^{th} technological capability to the system.

To calculate the overall discounted cost of the candidate path, the initial cost of the alternative base system is added to the discounted cost of each technological capability that is added to the candidate path. The following equation is used to compute the overall discounted cost of a candidate path:

$$ODC = IC + \sum_{j=0}^{M} DC_j \qquad (8)$$

Where ODC is the overall discounted cost of a candidate path, IC_j is the initial cost of buying the alternative base system, M is the total number of technological

capabilities that are added to a candidate path, and DC_j is the discounted cost of adding the j^{th} technological capability.

Figure 24 illustrates how the above calculations are used to calculate the overall discounted value and cost of the first candidate path.

VALUE AND COST OF A CANDIDATE PATH

YEAR	0	1	2	3	4	5
CANDIDATE PATH	NTCS - A	A	B	C	E	F
FUNCTIONS AUTOMATED	None	None	Mapping	Overlays	None	Info Exch
VALUE	0	0	1	1	0	1
DISCOUNTED VALUE	0	0	0.9	0.85	0	0.75
COST	1500K	400K	237K	237K	100K	473K
DISCOUNTED COST	1500K	363.6K	171K	155.5K	68.3K	293.7K

OVERALL DISCOUNTED VALUE OF THE CANDIDATE PATH = 0.9 + 0.85 + 0.75 = 2.5

OVERALL DISCOUNTED COST OF THE CANDIDATE PATH = 1500 + 363.6 + 171 + 155.5 + 68.3 + 293.7
= 2552.1K

Figure 24: Computation of the Discounted Value and Cost of a Candidate Path

The procedure for finding the overall discounted value and cost of a candidate path is simple. The first step involves determining when (or at which time periods) the candidate path will succeed in automating the functions of the target system. As can be seen in Figure 24, the first candidate path succeeds in providing the required automated

support to the mapping function in year two. The overlay function is obtained in year three and the information exchange function is obtained in year five. The second step requires the use of Equation (1) to compute the discounted value of each of the functions. The third step uses Equation (3) to calculate the discounted costs of the technological capabilities that are added to the system. The fourth and fifth steps use Equations (2) and (4) to compute the overall discounted value and cost of the candidate path. As can be seen from Figure 24, calculations for the first candidate path yield a discounted value of 2.5 and discounted cost of 2552.1K. Figure 25 shows the results of doing these calculations on the remaining candidate paths.

The next step of the framework discusses the selection of a candidate path using the values and costs that were calculated in this step.

DISCOUNTED VALUES AND COSTS OF THE CANDIDATE PATHS

	ALTERNATIVE BASE SYSTEMS			
	NTCS - A		IAS	
	PATH 1	PATH 2	PATH 3	PATH 4
DISCOUNTED VALUE	2.5	2.35	2.5	2.55
DISCOUNTED COST	2552.1K	2498K	2548K	2111.5K

Figure 25: The Discounted Value and Cost of Each Candidate Path

4. Select

The last step of the framework involves selecting the best candidate path. In this kind of decision, the "best" candidate path is the one that maximizes value subject to cost, resource, and risk constraints[26]. The rule or problem is stated as:

Maximize: **Value**

Subject to:
- **Cost**
- **Resource**
- **Risk**

An easy procedure for selecting the best candidate path given the data like that in Figure 25, is to first remove the candidate paths that don't satisfy at least one of the constraints from consideration. For the purpose of the illustration, say a budget of 2500K has been allocated for the C^3 system and that all candidates meet the resource and risk constraint. From Figure 25, candidate paths one and three exceed the established cost constraint, so they will not be considered. The next step is to select from the remaining candidate paths, the one that has the greatest value. For the illustration, candidate path four is selected[27].

[26] While this framework does not expand on the resource and risk constraint, they are still important issues that deserve a fair amount of attention for an actual evaluation.

[27] Candidate path four had the greatest value because it succeeded in automating some of the functions sooner than the other paths. It also had the least cost because the more expensive technological capabilities were added later in its path, which allowed them to take advantage of the discounting.

C. CONCLUSIONS

The illustration is intended only to give the reader a general idea of how to apply the concepts and procedures of this framework. For that purpose, the illustration is an extremely simplified one. Evaluations of actual systems would begin with a much bigger function/capability table for the definition of the target system functions and capabilities and would require more data. Nonetheless, the steps of the framework are fairly simple to follow and flow logically from one step to the next. The tables and data produced by this framework provide the decision makers with invaluable insight into how the various alternatives will change over time and may highlight evolutionary issues that have been overlooked in the past. This framework will result in decisions that have taken into account the difficult, but ever present, temporal component of evolving C^3 systems.

V. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

1. The C^3 Systems Procurement Environment

Chapter II presented a discussion of the technology initiatives that will impact C^3 systems. The Evolutionary Acquisition concept was introduced and topics such as Non-Developmental-Items, Commercial-Off-the-Shelf products, and open architecture standards were presented. It is important that the procurement environment in which C^3 systems are procured be understood by the evaluators. Important factors of the procurement environment that effect C^3 systems include; the recent increased rate of technological change, the mandated use of the Evolutionary Acquisition concept, the use of NDI and COTS products, and the evolving open architecture standards.

2. Current Frameworks

Chapter II also presented a cross-section of some of the current C^3 system evaluation frameworks. The Mission-Oriented Approach, the Modular Command and Control Evaluation Structure, and the COEA team's evaluation approach were discussed and their applicability to current C^3 systems evaluation highlighted. None of these frameworks or methodologies specifically deal with the temporal component of C^3 systems.

3. The New Framework

Chapter III presented a new framework that focuses the evaluation of alternatives on their evolutionary upgrade paths. The framework presents a method that could be useful to decision makers in choosing between alternative C^3 systems. The framework contains four steps:

1. Define target system functions and capabilities.
2. Define all viable upgrade paths from each alternative base system to the target system; each path becomes a candidate path.
3. Develop discounted value and discounted cost for each candidate path.
4. Select the candidate path that maximizes value subject to stated cost, resource, and risk constraints.

Methods and procedures for accomplishing each step was presented.

4. The Illustration

Chapter IV provided an illustration of the framework. The illustration focused on the Marine Corp's TCO system described in Chapter I. The illustration clarified how the methods of the framework can be applied.

B. CONCLUSIONS

1. The C^3 Systems Procurement Environment

The following conclusions can be made in regard to the environment in which C^3 systems are procured

1. That C^3 systems must capitalize on emerging technologies to remain mission capable.

2. That C^3 systems will incorporate evolutionary upgrades throughout their useful life cycle if procured through evolutionary acquisition.

3. That most of these evolutionary upgrades will be composed of NDI or COTS products that adhere to "open system" standards.

4. That current evaluation frameworks do not base their evaluations on the temporal component of C^3 systems.

2. The Framework as an Effective Tool for Evaluation

The new framework presented here offers an alternative approach to C^3 systems evaluations. The framework's methods for dealing with upgrade paths can be widely applied to many systems. C^3 systems of today and in the future will constantly change to keep up with state-of-the-art technologies. This aspect, called the temporal component, is directly addressed by this framework.

This framework can be a very useful tool for evaluating C^3 systems or subsystems that will undergo many evolutionary upgrade changes throughout their useful life cycle. The author concludes that evaluations of alternatives can be based on cost/benefit analysis performed on the perceived future upgrade paths of the alternatives.

3. The TCO Problem

The TCO program will no doubt go through many changes during its life cycle. The concept is a valid one and it is greatly needed to support the warfighters in today's environment

It is almost certain that some new baseline system will be bought to fulfill the TCO requirements. The next upgrade to TCO will become a new baseline system. This baseline system will form the core on which evolutionary upgrades will be incrementally added during its useful life cycle. Several different acquisition strategies are currently being considered by the project office, but one thing is certain about the program, many periodic upgrades will be integrated into the system. At each decision point, choices will have to be made as to which upgraded product to buy. This framework could be used at these subsequent decision points to help the USMC pick the "best" product.

C. RECOMMENDATIONS

This framework represents an initial effort at basing the evaluation of alternatives on their future evolutionary upgrade paths. General concepts and procedures were introduced. Areas that could benefit greatly by further research include:

1. More streamlined methods for determining target system functions and capabilities.
2. Methods that more accurately predict future upgrade technological capabilities and costs.
3. Procedures that would expand the framework to include evaluations of the uncertainty and risk issues.

APPENDIX A: GLOSSARY

ACE	Aviation Combat Element
ACMC	Assistant Commandant of the Marine Corps
ADM	Acquisition Decision Memorandum
ADPE-FMF	Automatic Data Processing Equipment-Fleet Marine Force
AE	Acquisition Executive
AFATDS	Advanced Field Artillery Tactical Data System
AHP	Analytical Hierarchy Process
AIC	Automated Information Center
AOA	Amphibious Operational Area
APO	Acquisition Project Officer
ARC	Atlantic Research Corporation
ASD	Assistant Secretary of Defense
ASP	Acquisition Strategy Plan
ASPO	Acquisition Sponsor Project Officer
ATACCS	Army Tactical Automated Command and Control System
ATCCS	Army Tactical Command and Control System
ATDL-1	Army Tactical Data Link-1
ATO	Air Tasking Order
AUTODIN	Automatic Digital Network
C^2	Command and Control
C^2MP	Command and Control Master Plan
C^3	Command, Control, and Communications
C^3I	Command, Control, Communications, and Intelligence
C^4I	Command, Control, Communications, Computers, and Intelligence

C^4I^2	Command, Control, Communications, Computers, Intelligence, and Interoperability
CATF	Commander Amphibious Task Force
CE	Command Element
CECOM	U.S. Army Communications-Electronics Command
CEO	Chief Executive Officer
CG	Commanding General
CIM	Corporate Information Management
CIP	Combat Information Processor
CMC	Commandant of the Marine Corps
COC	Combat Operations Center
COEA	Cost and Operational Effectiveness Analysis
COTS	Commercial-Off-The-Shelf
CP	Command Post
CSI	Command Systems Incorporated
CSSE	Combat Service Support Element
CTIS	Command Tactical Information System
DCA	Defense Communications Agency
DISA	Defense Information Systems Agency
DMA	Defense Mapping Agency
DoD	Department of Defense
DOS	Disk Operating System
DPM	Deputy Program Manager
EA	Evolutionary Acquisition
EPLRS	Enhanced Position Location and Reporting System
FIPS	Federal Information Processing Standard
FMF	Fleet Marine Force
GCE	Ground Combat Element
GOR	General Operational Requirement

GOSIP	Government Open System Interconnection Profile
GUI	Graphical User Interface
HQMC	Headquarters Marine Corps
IAS	Intelligence Analysis System
IEC	International Electrotechnical Committee
ISO	International Standards Organization
JTIDS	Joint Tactical Information Dissemination System
LAN	Local Area Network
MAGTF	Marine Air Ground Task Force
MARCORSYSCOM	Marine Corps Systems Command
MCASS	MTACCS Common Application Support Software
MCCDC	Marine Corps Combat Development Command
MCES	Modular Command and Control Evaluation Structure
MCHS	MTACCS Common Hardware Support
MCOTEA	Marine Corps Operational Test and Evaluation Activity
MCS	Maneuver Control System
MCTSSA	Marine Corps Tactical Systems Support Activity
MOA	Mission Oriented Approach
MOE	Measure of Effectiveness
MOFE	Measure of Force Effectiveness
MOP	Measure of Performance
MORS	Military Operations Research Society
MEF	Marine Expeditionary Force
MEU	Marine Expeditionary Unit
MIFASS	Marine Integrated Fire and Air Support System
MNS	Mission Need Statement
MTACCS	Marine Corps Tactical Automated Command and Control System
NDI	Non-Developmental-Item
NMSD	National Military Strategy Document

NTCS-A	Naval Tactical Command System - Afloat
O&S	Operations and Support
OMB	Office of Management and Budget
PM	Program Manager
POSIX	Portable Operating System Interface - UNIX
R&D	Research and Development
RDT&E	Research Development Testing & Evaluation
SMART	Simple Multi-Attribute Rating Technique
SOCEX	Special Operations Command Exercise
TCIM	Tactical Communications Interface Module
TCO	Tactical Combat Operations system
TNS	Tactical Network Server
US	United States
USMTF	United States Message Text Formats
USPACOM	U.S. Pacific Command
WAN	Wide Area Network

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